

Comparative Treatment Planning using Secondary Cancer Mortality Calculations

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Abstract

Calculations of mortality due to secondary cancer have been investigated for its use in comparative treatment planning. A patient with Hodgkin's disease has been chosen as an example and has been planned with different radiation treatment modalities using photons and protons.

The ICRP calculation scheme has been used to calculate mortality from dose distributions. To this purpose target volumes as well as critical structures have been outlined in the CT set of a patient with Hodgkin's disease. Dose distributions have been calculated using conventional as well as intensity modulated treatment techniques using photon and proton radiation. From the mean doses of each organ the mortality has been derived.

Our work suggests that calculations of mortality can be useful in comparative treatment planning. Such mortality calculations can be helpful to find decisions between radiotherapy treatment techniques (intensity modulated or conventional treatment) or between different types of radiation (photons, electrons, protons, neutrons).

KEYWORDS: Comparative treatment planning, secondary cancer, photons, protons.

1. Introduction

Comparative treatment planning is an important method for quantifying advantages and disadvantages of different treatment techniques in radiation therapy. Such comparisons can be useful in reaching a decision on what kind of treatment should be used for patient irradiation. The usual way of judging plans is to compare physical dose distributions or biological parameters. The commonly used biological models for characterising treatment plans are extracted from the physical dose or dose-volume-histograms which are based on the deterministic damage of cells. In other words the probability of complication in a particular organ is a function of both dose and irradiated volume.

In this work we use a different method of comparison based on the concept of stochastic damage of cells as is commonly used in radiation protection. In the last decades radiation therapy has improved significantly and as a consequence cure rates have also increased. As a result, there are now many long term survivors of cancer who are at risk of late effects of therapy, including secondary cancers. It is estimated that more than 0.1% of all people between the ages of 16 and 44 will be a survivor of childhood cancer by the year 2000 [1]. In this report we estimate the occurrence of secondary cancer that may result from different treatment regimes. These estimates have been calculated from the different computed dose distributions and are based on the guidelines of the International Commission of Radiation Protection (ICRP). Although

the absolute mortality rates calculated here must be viewed with great caution, we believe the values can be used as an indicator for the relative risks of different treatment techniques.

Four different treatment techniques have been investigated in this context, conventional photon irradiation, intensity modulated photon irradiation, single field protons and multiple field protons.

2. Methods and materials

2.1. Description of the patient

We chose for the planning comparison a patient with Hodgkin's disease as cure rates are high [1]. Prior to treatment, a planning computed tomography study (CT) consisting of 36 slices with a separation of 1 cm was obtained. Planning target volumes (PTV) as well as critical structures were outlined in the CT-slices. For all the following calculations a prescription dose of 36 Gy was assumed.

2.2. Treatment planning

Two field 6 MV photon plan (PH2). A conventional mantle field plan was calculated with 6 MV photons and two opposed fields using CADPLAN V3.1*. The unblocked field size was 32 cm × 30 cm with equal field weights from 0 and 180 degree and a

* Varian Oncology Systems, Palo Alto (USA).

source to surface distance of 100 cm. Individually contoured, anteriorly and posteriorly lung blocks as well as blocks to protect the humeral heads were used in the planning.

Nine fields 15 MV intensity modulated photon plan (PH9). For the calculation of the intensity modulated photon treatment plan software established at the Paul Scherrer Institut was used [2,3]. This code which was originally developed for calculating intensity modulated proton plans, has been adapted to work with photons using a 15 MV photon kernel obtained from the Deutsches Krebsforschungszentrum [4]. The optimisation algorithm is essentially the same as that developed by Bortfeld et al. [5]. Nine equally spaced fields were used starting from 0 degree with steps of 40 degrees. The constraints of the intensity modulation were a homogeneous dose of 36 Gy in the PTV and, as it is the most sensitive organ, a constraint of 17.5 Gy on 1/3 of the volume of the lungs.

One field 160 MeV proton plan (PR1). The one field proton plan was obtained with the standard PSI treatment planning software using the spot scanning technique [3]. The field was calculated for 0 degree beam incidence and the spot weights were determined using the single constraint of a homogenous dose of 36 Gy in the PTV. Although an optimisation regime was used to obtain the spot weights it should be noted that no normal tissue constraints are included in the standard planning and this plan therefore can be considered to be the proton equivalent of the two field photon plan.

Nine fields 177 MeV proton plan (PR9). The nine field proton plan was computed using the PSI proton IMRT treatment planning [3]. The version of the code including three dimensional multi-field optimisation has been used to modulate the intensity of individual narrow Bragg peaks in three dimensions. Nine equally spaced fields were applied starting from 0 degree with steps of 40 degrees. Due to the different maximum ranges of the protons required to reach the distal end of the target from each beam port a number of different maximum proton energies are used (0, 80, 120, 160, 240, 280 degree: 160 MeV; 40, 200, 320 degree: 177.25 MeV). To avoid unnecessary dose to the lungs a patch field technique was used in which the central part of the PTV was covered by the fields from 0, 40, 160, 200 and 320 degree, the right lateral part from 240 and 280 degree and the left lateral part from 80 and 120 degree. The constraints used in the optimisation were identical to that used in the nine field photon plan (PH9).

2.3. Calculation of mortality due to second cancer

The calculation of second cancer mortality is based on the computed dose distribution in the patient and the method described by ICRP 60 [6] for extracting from the average organ dose the total mortality of the patient due to late effects of therapy. From the

computed treatment plans we determine the average doses H_T in the outlined volumes. The ICRP 60 (98) recommends to use the probability coefficients of death for the single tissues and organs for computing mortality when the equivalent dose is not distributed homogeneously in the whole body [6]. This is the case when a patient is treated with irradiation, as most of the dose is concentrated around the target. The probability of death due to irradiation of a single organ M is taken from the ICRP 60 report and listed in Table I. The total mortality is then determined by summing the probabilities of the individual tissues:

$$M = \sum_T M_T H_T \quad (1)$$

3. Results

3.1. Calculation model of cancer mortality

The mortality resulting from a conventional treatment of Hodgkin's disease with a classical mantle field is calculated to be 36% (Table 1). This value is in good agreement with the data from literature. Bhatia et al. [7] found that the risk of solid tumours after Hodgkin's treatment continued to increase beyond 15 years and approached 30% at 30 years. The organ specific mortalities are in satisfying agreement with the numbers from investigations on secondary cancer from Hodgkin's disease [7, 8]. The only major difference is the predicted mortality for breast cancer which is for the mantle field calculated to be 0.03% per year compared for example with the absolute risk estimates of Hancock and Hoppe [8] who get 0.2% per year. This difference could be due to the fact that usually the investigations of secondary cancer incidence include a large fraction of children. According to Hancock and Hoppe the risk for breast cancer for women treated before 20 years of age is 20 times higher than for women treated after 30 years of age. The organ specific mortality for breast cancer given by ICRP 60, however, is evaluated for women of all ages.

3.2. Comparison of conventional treatment techniques with IMRT techniques

Our calculations indicate that for treatment plans of Hodgkin's disease the difference in second cancer mortality is independent of the treatment modality. The probabilities in dying of second cancer is for a mantle treatment with two opposed photon fields 35.6% and for a complicated nine fields intensity modulated photon treatment plan 34.6%. This result seems to be independent of the type of radiation, as the single field proton plan results in a mortality of 26.8% compared to a mortality of 27.6% with the nine field intensity modulated treatment plan.

Table I – Effective mortality for single organs of interest and resulting total mortality for four different treatment plans (PH2: 2 fields-6MV-photons; PH9: 9 fields-15MV-photons-IMRT; PR1: 1 field-160MeV-protons; PR9: 9 fields-177MeV-protons-IMRT).

Name of organ	Organ coefficient of probability of dying M_T	Mortality due to second cancer $M_T H_T$ [%]			
	[% Sv ⁻¹]	PH2	PH9	PR1	PR9
Body (in CT, without other organs)	0.25	4.50	2.94	1.23	1.56
Liver	0.15	0.32	0.04	0.0	0.01
Breast	0.20	0.98	1.25	0.09	0.40
Lung	0.85	13.92	16.25	11.71	11.46
Bone: red marrow	0.50	1.71	1.11	0.64	0.87
Bone: surface	0.05	0.60	0.39	0.23	0.31
Thyroid gland	0.08	3.07	2.86	2.88	0.29
Esophagus	0.30	10.53	9.77	9.99	10.04
Total mortality M [%]	$\Sigma M_T H_T$	35.63	34.61	26.76	27.55
Relative total mortality	M / M_{PH2}	1	0.97	0.75	0.77

3.3. Comparison of photon treatment with proton treatment

Comparing photon with proton treatment planning shows the interesting result that proton treatment plans can reduce the mortality by around 25% compared to photons. It is also noteworthy that this difference is independent of the delivery technique used. The ratio of mortality of a single field proton plan to the two fields photon plan is 0.75 and the same is 0.77 for the intensity modulated treatment plans. This could be a consequence of the different depth dose curves corresponding to the different particles. The integral dose of the protons is independent of the treatment technique by approximately a factor of two smaller than the photon integral dose.

4. Conclusion

Our work suggests that calculations of mortality can be useful in comparative treatment planning. The mortality calculations on which we reported in this paper can be helpful to find decisions between radiotherapy treatment techniques (intensity modulated or conventional treatment) or between different types of radiation (photons, electrons, protons, neutrons).

By looking particularly at the mortality due to secondary cancer resulting from the irradiation of Hodgkins disease we found that intensity modulated treatments will give little or no improvement over

conventional treatments. However proton treatment can result in a lower mortality than photon treatment.

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