Planning comparison between intensity modulated radiation therapy and intensity modulated proton therapy in a case of head and neck cancer

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Abstract. In this work, we made the comparison between IMRT plan and IMPT plan for a head and neck case. We used Prowess Panther to perform IMRT plan and LAP-CERR for IMPT plan. The result showed that IMPT plan had better coverage than IMRT plan. In the IMRT plan, normal structures received higher dose with higher volume. Especially, the maximum dose of spinal cord is 31.5 Gy (RBE) using IMRT technique compared to 13.5 Gy (RBE) using IMPT technique. These results showed that IMPT is beneficial for head and neck cancer compared to IMRT technique.

1. Introduction

Currently, traditional radiation therapy x-rays are still the most common type of radiation in curing cancer. However, the persisting problem is that significant dose delivered to normal tissue because of the characteristics of interaction of photons with matter even with the most advanced delivery technique. Proton therapy is the technique producing better conformity to target and better sparing to organs at risk. In this paper, Intensity Modulated Proton Therapy (IMPT) and Intensity Modulated Photon Therapy (IMRT) plans are generated for a head and neck patient. To make IMRT plans we used Prowess Panther, a commercial Treatment Planning System (TPS) and LAP-CERR (The Laser Accelerated Particle [1]- The Computational Environment for Radiotherapy Research [2]). The evaluation and comparison of the two kinds of radiation treatment plans were performed in term of physical quantity based on Dose Volume Histogram (DVH) and dose statistics for both target and organs at risk.

2. Methods

In this section, we will introduce some main features of dose algorithm and dose optimization of Prowess Panther and LAP-CERR. The definitions of PTV and PRVs and dose requirements also will be described here.

2.1. Prowess Panther

2.1.1. Dose calculation algorithm

Collapsed cone convolution of radiant energy for photon dose calculation in heterogeneous media [3, 4] has been used to calculate absorbed dose. This method assumed transported energy process
consisting of two steps energy release and energy deposition. In the first step, the energy released by the primary photon is characterized by \( T(\vec{r}) \). And then \( T(\vec{r}) \) is distributed by secondary particles such as electrons, positrons, scatter photon, Auger electrons, and so on according to Kernel- the point spread function describing the spatial spread of energy from each interaction point. To simplify the calculation \( D(\vec{r}) \), the Cartesian coordinates must be discrete. To make Cartesian coordinates tractable, the collapsed cone approximation suggested by Anders Ahnesjo [3] is made. The main idea is that all energy released into coaxial cones of equal solid angle, from volume elements on the cone axis, is rectilinearly transported, attenuated, and deposited in elements on the axis.

2.1.2. Dose optimization algorithm

The dose optimization algorithm DAO (Direct Aperture Optimization) invented by Shepard et al. [5] has been used in Prowess Panther. The special point in DAO is that the optimized variables in DAO are leaf positions for each aperture and the weight assigned to each aperture. Therefore, it can significantly reduce the number of beam segments and the number of monitor units. Besides, the use of the simulated annealing algorithm to optimize is to avoid local minima.

2.2. LAP-CERR
2.2.1. Dose calculation algorithm

The pencil beam dose calculation has been used in LAP-CERR. Then the dose for the point of interest at \( \vec{r} \) (see in Figure 1) is the sum of the doses of all pencils [6, 7, 8]. The dose of each pencil beam is the product of two quantities, a central axis depth dose \( D(z, E_0) \) and a lateral dose \( L(\vec{r}, z, E) \).

\[
D(\vec{r}, z, E) = c \cdot D(z, E) \cdot L(\vec{r}, z, E) \tag{1}
\]

where \( c \) is the correction factor due to inverse square law, calculated by

\[
c = \left( \frac{d_s}{d_p} \right)^2 \tag{2}
\]

where \( d_s \) is the distance from the source to the isocenter and \( d_p \) is the distance from the source to the calculated point.

The lateral dose \( L(\vec{r}, z, E) \) can be estimated to the first order by a Gaussian distribution suggested by Moliere as following

\[
L(\vec{r}, z, E) = \frac{1}{2\pi \sigma^2 (z, E)} \exp \left( -\frac{(\vec{r} - \vec{r}_0)^2}{2\pi \sigma^2 (z, E)} \right) \tag{3}
\]

Where \( \vec{r}_0 \) is the position of the central beamlet axis and \( \sigma^2 (d, E) \) is the standard deviation of the Gaussian distribution depending on the depth \( z \) in the material and the initial energy \( E \) of the proton beam. The standard deviation \( \sigma^2 (d, E) \) is calculated by adding in quadrature the standard deviation due to the beginning size of the pencil beam and the multiple Coulomb scattering from the patient.
\[ \sigma^2 = \sigma_a^2 + \sigma_b^2 \]  

(4)

Because the beam delivery is spot scanning method, \( \sigma_a \) is about 0.025 cm. \( \sigma_b^2 \) called lateral Spread Square, is the standard deviation due to multiple Coulomb scattering in the lateral direction of the patient. \( D(z, E) \) in formula (1) and \( \sigma_b \) in formula (4) are estimated by the tabulated approach from depth dose curve and lateral spread square. This database had been compiled by Monte Carlo simulation.

The dose deposited by all pencil beams for the point of interest at \( \vec{r} \) is the sum of dose of each pencil beam deposited energy at \( \vec{r} \)

\[ D(\vec{r}) = \sum_i D(\vec{r}_i, z_i, E_i) \]  

(5)

2.2.2. Dose optimization algorithm

Objective function

The objective function based on the dose criteria. These are the important criteria because the dose distribution across the target volume is required to be homogeneous. In LAP-CERR, the dose constraints for organs at risk is set equal to zero, and the dose to target is set to the prescribed dose. The total objective function is given as following

\[ \text{OF} = \sum_{n=1}^{N} \omega_{nT} \sum_{i=1}^{N_n} (D_{iT} - D_{nT})^2 + \sum_{m=1}^{M} \omega_{mOA} \sum_{j=1}^{N_m} (D_{jOAR} - D_{mOAR})^2 \]  

(6)

Where \( \omega_{nT}, \omega_{mOAR} \) are the important factors for the \( n \)th target and the \( m \)th critical organ respectively. \( D_{iT}, D_{nT} \) is the calculated dose of the \( i \)th voxel and the prescribed dose in the \( n \)th target; \( D_{jOAR}, D_{mOAR} \) are the calculated dose of the \( j \)th voxel and the dose constraint in the \( m \)th organ at risk. \( N, M \) is the total number of targets and organs at risk correspondingly. The \( N_n \) and \( N_m \) are the total numbers of voxels in the \( n \)th target and the \( m \)th organ at risk. In LAP-CERR, to adjust the importance factors using Matlab file readSettingsPatient.mat.

Optimization algorithm

Optimization algorithm in CERR is Newton method with diagonal Hessian approximation and performed by function quadpod in Matlab.

2.3. Patients

We made the comparison between IMPT plans and IMRT plans for a head and neck patient.

Treatment prescription

| Volume (\%) | Dose (Gy (RBE)) | Max dose (Gy (RBE)) | References |
|-------------|-----------------|---------------------|------------|
| Brainstem   | 1%              | 60                  | 54         | RTOG 0225 |
| Parotid gland (one) | 50%             | 30                  | -          | RTOG 0619 |
| Spinal cord | 0.03            | 48                  | -          | RTOG 0619 |
| Eyes        | Mean            | 35                  | -          | RTOG 0225 |

The prescribed dose was 60 Gy (RBE) with Relative Biological Effectiveness (RBE) = 1.1 according to ICRU 78 [9, 10] to the ICRU Reference point. The dose constraints of critical structures were from some references as in Table 1.

Beam Parameters and Delivery technique: four beams at gantry angle of 90⁰, 270⁰, 160⁰ and 340⁰ were used in proton therapy. Proton energy was from 70 MeV to 250 MeV with step of 10 MeV and the
width energy of 6 MeV. The energy solution of the initial particle fluency spectrum was 0.1 MeV. In IMRT plan, we employed 12 equispaced fields of $0^\circ$, $30^\circ$, and so on with photon energy of 6 MeV. Laser accelerated protons imparted to the patient by spot scanning technique [14], whereas step-and-shoot delivered photon beam.

**Volume Definitions**: the CTV was extended by 12 mm to create PTV. All of critical organs in Table 1 had the same margin of 5 mm [13].

2.4. **Treatment plan analysis: Dose Volume Histogram-DVH and Dose Statistics**

**Dose Volume Histogram –DVH**: this is the most basic tool to look at the dose distribution of tumour and organs at risk and used popularly in treatment planning. It shows how many the percentage of volume receiving the dose smaller or equal a certain dose. **Dose Statistics**: we chose some important values on DVH including mean dose, maximum dose, and minimum dose to see the difference between these two kinds of radiation therapy.

3. **Result and Discussion**

3.1. **Dose Volume Histogram**

![Dose volume histograms](image)

**Figure 2.** Dose volume histograms of PTV, Cord, right Parotid gland, left Parotid gland, Brain stem and right eye of IMRT plans (dash line) and IMPT plans (solid line).

Dose-volume histograms of PTV, Cord, right Parotid gland, left gland, brain stem and right eye of IMRT and IMPT plans are presented in Figure 2.
Both photon and proton plans achieved the rather good coverage of PTV, but IMPT plan is better. The maximum dose to PTV is 107.5% of prescribed dose, lower than 112.5% from IMRT plan. The minimum dose of two plans are the same equal to 87.5%. This value is a bit lower than the dose requirement of 95% due to the buildup effects of the PTV is next the skin. All of critical organs received much lower doses than the dose-volume limits as shown in Table 1. Especially, for the spinal cord, the dose of IMPT plan is significantly reduced and much lower than of IMRT plan. The doses received by brainstem and the right eye is negligible in both plans. For the right parotid, the IMPT plan received higher dose than IMRT plan. However, the maximum dose of IMPT plan is only about 22% of prescribed dose. For the left parotid, the dose of IMRT plan is a bit higher than IMPT plan.

3.1.1. Dose statistics: Mean Dose, Minimum dose and Maximum dose

| OARs       | Mean dose Gy (RBE) | Minimum dose Gy (RBE) | Maximum dose Gy (RBE) |
|------------|--------------------|-----------------------|-----------------------|
|            | IMRT   | IMPT    | IMRT   | IMPT    | IMRT   | IMPT    |
| Brainstem  | 1.74   | 1.50    | 1.50   | 1.50    | 1.74   | 1.50    |
| Parotid gland (left) | 20.16  | 22.50   | 1.50   | 1.50    | 64.50  | 64.50   |
| Parotid gland (right) | 6.81   | 2.50    | 1.50   | 1.50    | 7.50   | 13.50   |
| Right eye  | 8.46   | 4.50    | 1.50   | 1.50    | 31.50  | 13.50   |
| PTV        | 61.44  | 61.50   | 52.50  | 52.50   | 67.5   | 64.50   |

In this table, the significant differences are bold for the worse case which is IMRT for most of criteria. The minimum doses of two kind of plans were the same. The maximum dose of spinal cord is 31.5 Gy (RBE) using IMRT technique compared to 13.5 Gy (RBE) using IMPT technique (Table 2). In IMRT plan, higher volumes were in higher dose regions so that the mean doses of them were also higher. The reasons were that the use of many radiation fields of IMRT plan, twelve equispaced fields, and the higher penetration passing through the patient made IMRT plan had some disadvantages compared to IMPT plan.

4. Conclusion
The results of our study show that IMPT had the ability of better coverage of PTV than IMRT. Significant dose reduction with the IMPT plan was clearly observed for nearly all normal structures. Especially, the maximum dose of spinal cord is 31.5 Gy (RBE) using IMRT technique compared to 13.5 Gy (RBE) using IMPT technique. IMPT will be beneficial for head and neck cancer compared to IMRT technique.

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