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Comparison of TDF and LQ models using the bioeffects algorithm of a treatment planning system

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In this study, two examples, first with two-field AP/PA plans and second with four-field plans are evaluated for Co-60 beams using the bioeffects program of the Radiation Oncology Computer System (ROCS) treatment planning system. The bioeffects algorithm enables the summation of two or more treatment plans. Biomodifier tables, which convert the values of dose per fraction delivered over a period of time to Time Dose Fractionation (TDF) are included with the software. The biomodifier table is a standard ROCS two-dimensional table. By using the linear-quadratic (LQ) model, the biological equivalent dose versus the physical absorbed dose was determined and input as a new biomodifier table. The distribution of TDF values and the biological equivalent dose using the LQ model shows that the LQ model may be a better choice for a bioeffect algorithm. Furthermore, the LQ model may be implemented in the ROCS system.

Key words: neoplasms-radiotherapy; computer-assisted; bioeffects algorithm, radiotherapy planning, radiation therapy, dose response relationship

Introduction

The Time Dose Fractionation (TDF) model[1] and the linear-quadratic (LQ) model[2] are theories that attempt to predict the biological effects which occur during a course of radiation therapy. The TDF model is based on the iso-effect dose as a function of either the overall time, or total number of fractions of treatment. TDF has been used for many years as a time-dose model in radiotherapy since it is simple to use. The LQ model is based on the linear-quadratic shape of the cell-survival curves. It is postulated that radiation can be divided into two components, the α component is more important at low doses, and the β component more important at high doses. The parameter α/β is the dose at which the fractional log cell kill for these two components is equal.[2]

In this study, two field AP/PA and four field plans are evaluated using the bioeffects program of the ROCS (Radiation Oncology Computer Systems, Carlsbad, California, U.S.A.) treatment planning system for Co-60 beams. The ROCS treatment planning system has a bioeffects algorithm[3] which supposedly enables the summation of two or more treatment plans. A treatment is defined as a series of contours with external beam data, or planes of brachytherapy data. Biomodifier tables, which convert the values of the dose per fraction delivered over a period of time to TDF, are included with the software. The table values were derived from work done by Orton.[4,5]

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The biomodifier table is a standard ROCS two-dimensional table. By using the LQ model, the biological equivalent dose versus the physical dose was determined and input as a new biomodifier table. The distribution is compared using the TDF and the LQ models.

Materials and methods

A contour with AP/PA separation of 25 cm and lateral separation of 38 cm was used for external beam planning. In the first example, a setup of 80 cm SSD with AP/PA 18 × 18 cm^2 Cobalt-60 beams was used to deliver 1.8 Gy/fraction to the mid-plane. In the second example, four fields equally weighted, with 18 × 18 cm^2 AP/PA and 10 × 18 cm^2 lateral fields, 80 cm SSD Cobalt-60 beams were used. A total of 45 Gy was delivered in 25 fractions. A typical external beam biomodifier table provided by ROCS will convert cGy/fraction to TDF for the number of fractions per week and the total number of fractions specified. In this case, five fractions per week were used.

The beam arrangement in this simple example was chosen to demonstrate the application of the different models, i.e., TDF and LQ using the ROCS system. The contour may be considered as a thoracic region where the spinal cord dictates the normal tissue tolerance.

Withers[6] and Scalliet[7] showed that calculation of isoeffect dose equivalencies when altering the fraction size can be done using the formula
where D is a reference total equivalent dose delivered at a given fraction size d and D' is the unknown total equivalent dose delivered at a new fraction size d'.

$$\frac{D'}{D} = \frac{d + \alpha/\beta}{d' + \alpha/\beta}$$

Using a α/β of 2 Gy for late reacting tissues,[7] and a fraction size of 1.8 Gy, the equivalent total dose may be computed, e.g., for the 1.9 Gy isodose line in the daily dose distribution, such that

Equivalent does using LQ model = (1.9 Gy × 25) × (1.9 + 2)/(1.8 + 2) = 48.8 Gy

The biological equivalent dose of 48.8 Gy corresponds to an absorbed dose of 47.5 Gy. Similar calculations were computed for daily doses from 0.2 to 2.2 Gy, and these values were input as a two-dimensional table in the ROCS bioeffect program.

Results

Figure 1 shows the total dose distribution from standard treatment planning using the ROCS system. A total dose of 45 Gy was delivered to the mid plane, while the maximum dose was 56 Gy, for a setup of 80 cm SSD with AP/PA Cobalt-60 beams.

Figure 2 shows the TDF isolines using the bioeffect algorithm of the ROCS system. The TDF value was about 70 at the mid plane with a maximum of 97.

Figure 3 shows the equivalent dose distribution calculated using the LQ model. Again, 45 Gy was delivered to the mid plane. The maximum biological equivalent dose was found to be 61 Gy.

Figure 4 shows the total dose distribution from standard treatment planning using the ROCS system. A total dose of 45 Gy was delivered to the mid plane, while the maximum dose was 46 Gy, for the four-field setup of 80 cm SSD.

Figure 5 shows the TDF isolines using the bioeffect algorithm of the ROCS system. The TDF value was about 70 at the mid plane with a maximum of 73.

Figure 6 shows the equivalent dose distribution calculated using the LQ model. Again, 45 Gy was delivered to the mid plane. The maximum biological equivalent dose was found to be 47 Gy.

Discussion

The bioeffects program of the ROCS system is limited to a single external plan, which may be used with a brachytherapy plan. The biomodifier tables provided by ROCS, however, are somewhat outdated. Orton[8] states that a TDF of 100 is roughly equivalent to normal connective tissue and skin tolerance. In the simple AP/PA setup example where the spinal cord may be the sensitive normal structure outside the target volume, the dose equivalent may approach the normal tissue tolerance. The TDF in the spinal cord region may only show a value of 70 to 80.

The LQ model may be implemented here to demonstrate its use in treatment planning. Comparing figures 1 and 3, the biological equivalent total dose is higher than the absorbed dose. This is demonstrated by the larger volume of the 50 Gy isodose, and the maximum biological dose equivalent of 61 Gy.

In the four-field example, the biological equivalent total dose (Figure 6) is also higher than the

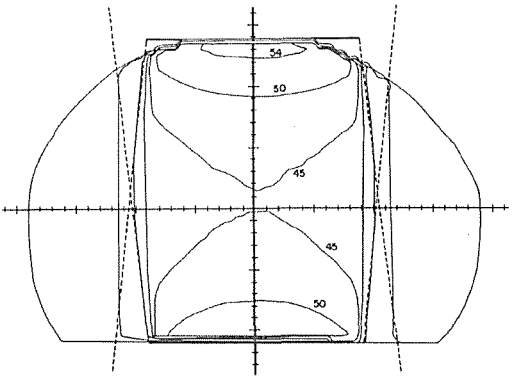

Figure 1. Total dose distribution from the regular treatment planning using the ROCS system. A total dose of 45 Gy was delivered to the mid-plane for the AP/PA setup. Numbers indicate the total dose (in Gy) to an isodose line.

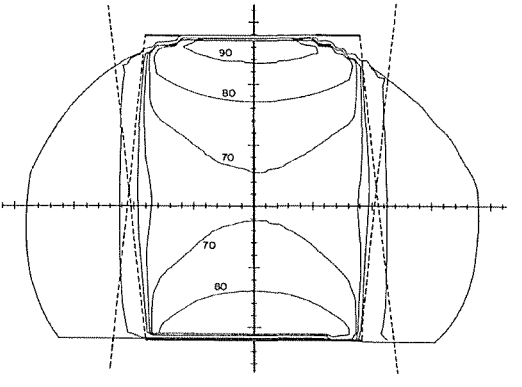

Figure 2. TDF isolines using the bioeffect algorithm of the ROCS system for the AP/PA setup.

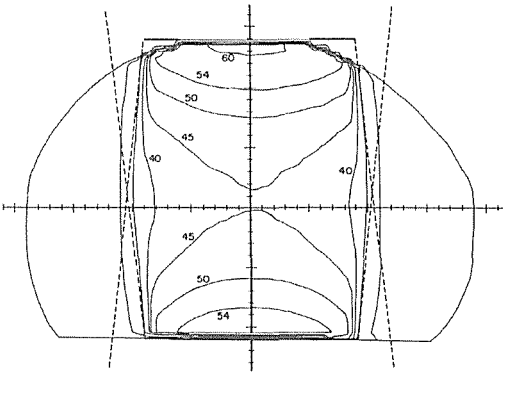

Figure 3. The biological equivalent dose distribution calculated using the LQ model for the AP/PA setup. Numbers indicate the total biological equivalent dose (in Gy) to an isodose line.

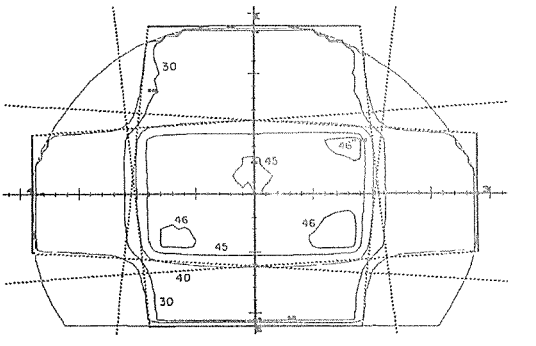

Figure 4. Total dose distribution from the regular treatment planning using the ROCS system. A total dose of 45 Gy was delivered to the mid-plane for the four-field setup. Numbers indicate the total dose (in Gy) to an isodose line.

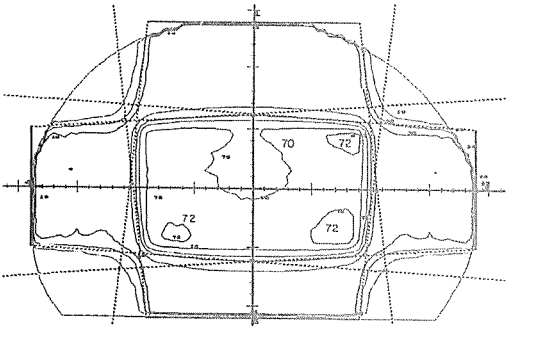

Figure 5. TDF isolines using the bioeffect algorithm of the ROCS system for the four-field setup.

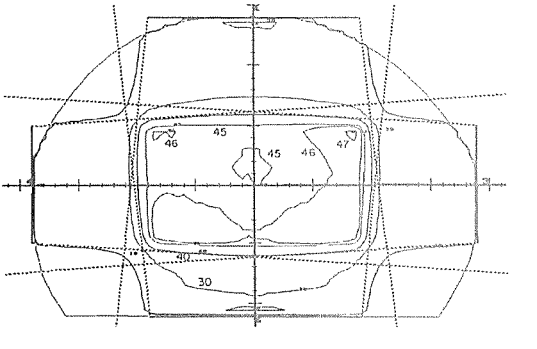

Figure 6. The biological equivalent dose distribution calculated using the LQ model for the four-field setup. Numbers indicate the total biological equivalent dose (in Gy) to an isodose line.

absorbed dose (Figure 4). This is demonstrated by a larger volume of the 46 Gy isodose, and a maximum biological dose equivalent of 47 Gy. Again, the TDF isolines in figure 5 do not give any useful information.

The biomodifier tables as provided by ROCS for the bioeffect algorithm have very limited use in treatment planning, since they utilize the TDF model. The LQ model is a better algorithm and it may be implemented easily in ROCS. Any model, however, will have to be used with caution since there are always limitations in its practical application.

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