

Calculation of Cumulative Biological Effective Dose Distributions for Multimodality Treatment Regimes

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Abstract

Purpose: Evidence has recently been reported supporting the role of stereotactic body radiotherapy (SBRT) as a supplemental treatment option in the form of a boost or salvage reirradiation following conventional radiotherapy. It may therefore be desirable to augment the process of physical dose summation in the cumulative plan evaluation process by constructing corresponding biological effective dose (BED) distributions that incorporate the biological effects of the different dose fractionation schemes required for multimodality treatments. To that end, we developed a computational process for calculating cumulative BED distributions for patients receiving conventional radiotherapy followed by SBRT.

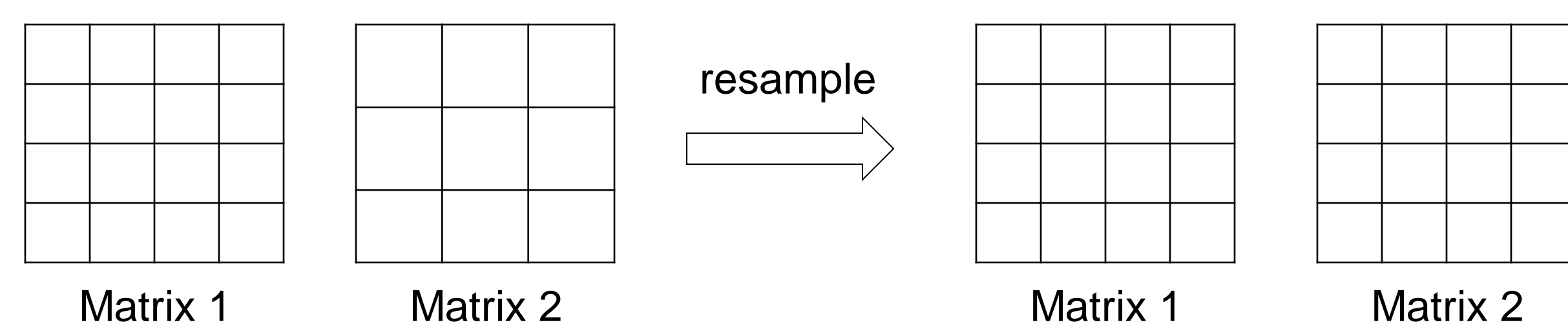
Method and Materials: We developed a program designed to accept two DICOM dose matrices, as calculated in standard treatment planning systems, and calculate the BED at each matrix element obeying the dose per fraction dependence in the BED formalism. It then calculates the cumulative BED distribution for multimodality treatment regimes by matrix summation and outputs the result in DICOM format. Two clinical head and neck IMRT cases (large field (2.13 Gy x 33) and small field (2 Gy x 32)) were evaluated as part of a pilot study to demonstrate the overall feasibility of the calculation scheme. Following clinical IMRT planning, each case was planned in a mock SBRT scenario (6 Gy x 5) where a smaller planning volume was drawn to simulate a boost or salvage reirradiation. The clinical IMRT and mock SBRT dose matrices were then processed to generate cumulative BED distributions.

Results: Our computational process was successful in producing cumulative BED distributions. For the large field IMRT case, the overall BED distribution beyond the initial treated volume was dominated by the initial IMRT course, whereas clear additive increase in the BED distribution beyond the initial treated volume was evident in the small field case.

Conclusions: Our initial pilot study has proven the feasibility of constructing cumulative biological effective dose distributions for patients receiving conventional radiotherapy followed by SBRT. Individual patient results will vary depending on relative size of the target volumes, location of the dose escalated volume, dose fractionation schemes, tissue specific α/β ratios, changes to the BED formalism, etc. Variations on these parameters will be the subject of further studies.

Part 1: Calculation Formalism

- Code written in Python 2.7.1 and utilizes the 'pydicom' package available at <http://code.google.com/p/pydicom>.
- The program accepts two DICOM dose matrices (2 or 3 dimensional).
- DICOM dose matrices are resampled using linear interpolation to ensure matching matrix resolution:



- The BED is calculated at each matrix element using the standard BED equation:

$$BED = nd \left(1 + \frac{d}{\alpha/\beta} \right)$$

n = number of fractions
d = dose per fraction at each matrix element
 α/β is user specified

- The cumulative BED distribution (external beam + SBRT) is calculated by matrix summation and is given by:

$$BED_{EXT+SBRT} = BED_{EXT} + BED_{SBRT}$$

- The program output is a single combined DICOM dose (biological effective dose) matrix that can be read into standard treatment planning systems or third party analysis software.

Part 2: Pilot Study

- The feasibility of the calculation scheme was demonstrated using two recent clinical head and neck IMRT cases.
- Patients were chosen for this pilot study based on initial target volume size and then separated into large- and small-field examples.
- Large-field dose = 2.13 Gy x 33 fractions for >95% target volume coverage.
- Small-field dose = 2.0 Gy x 32 fractions for >95% target volume coverage.
- Patients were mock planned for SBRT by contouring target volumes intended to simulate boost or salvage reirradiation volumes.
- Mock SBRT dose = 6.0 Gy x 5 fractions for >95% target volume coverage.
- IMRT and SBRT dose matrices were processed to generate cumulative 3-dimensional BED distributions.

Part 3: Results

- Figure 1 shows the results of the large-field head and neck BED distribution calculations (units are cGy_3).
- Figure 1A is an axial slice of the full 3-dimensional BED distribution for the large-field IMRT plan alone.
- Figure 1B is the same axial slice of the full 3-dimensional BED distribution for the mock SBRT plan alone.
- Figure 1C is an axial slice of the cumulative BED distribution.
- There is an increase in the cumulative BED distribution close to the dose escalated volume, but very little change in the 100 Gy_3 distribution (considered normal tissue tolerance) demonstrating that the cumulative BED distribution for this example is dominated by the IMRT treatment course.

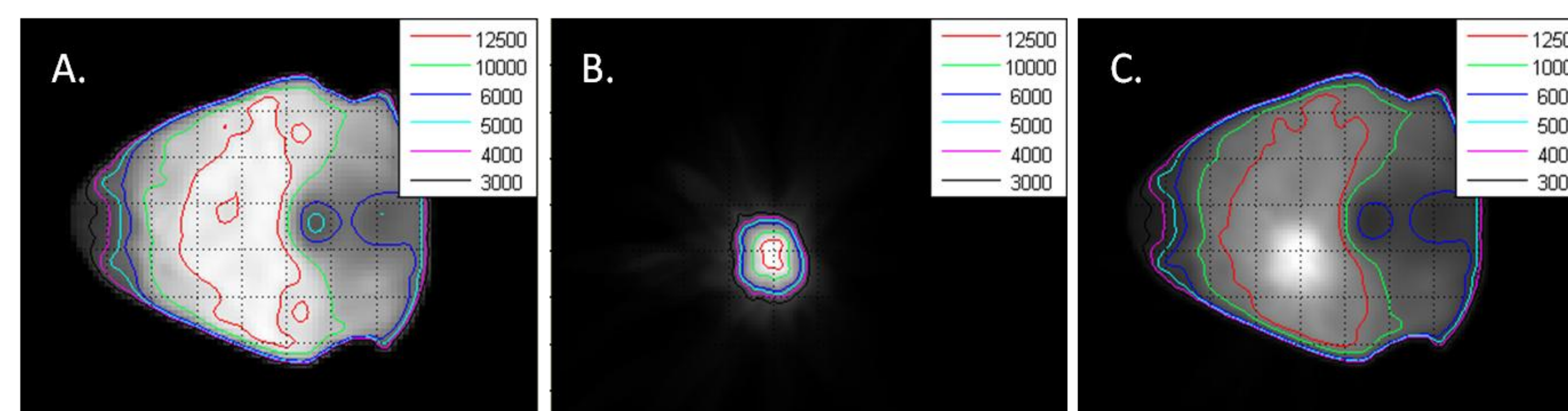


Figure 1. Representative single slices of full 3-dimensional BED distributions for large-field IMRT alone (A), SBRT alone (B) and the summation of IMRT and SBRT (C), Units are cGy_3 , 1 cm grid size.

- Figure 2 shows the results of the small-field head and neck BED distribution calculations (units are cGy_3).
- Figure 2A is an axial slice of the full 3-dimensional BED distribution for the small-field IMRT plan alone.
- Figure 2B is the same axial slice of the full 3-dimensional BED distribution for the mock SBRT plan alone.
- Figure 2C is an axial slice of the cumulative BED distribution.
- Not only is there an increase in the BED distribution close to the dose escalated volume, but there is also clear additive increase in the 100 Gy_3 distribution indicating that normal tissues close in proximity to the dose escalated volume may reach tolerance.

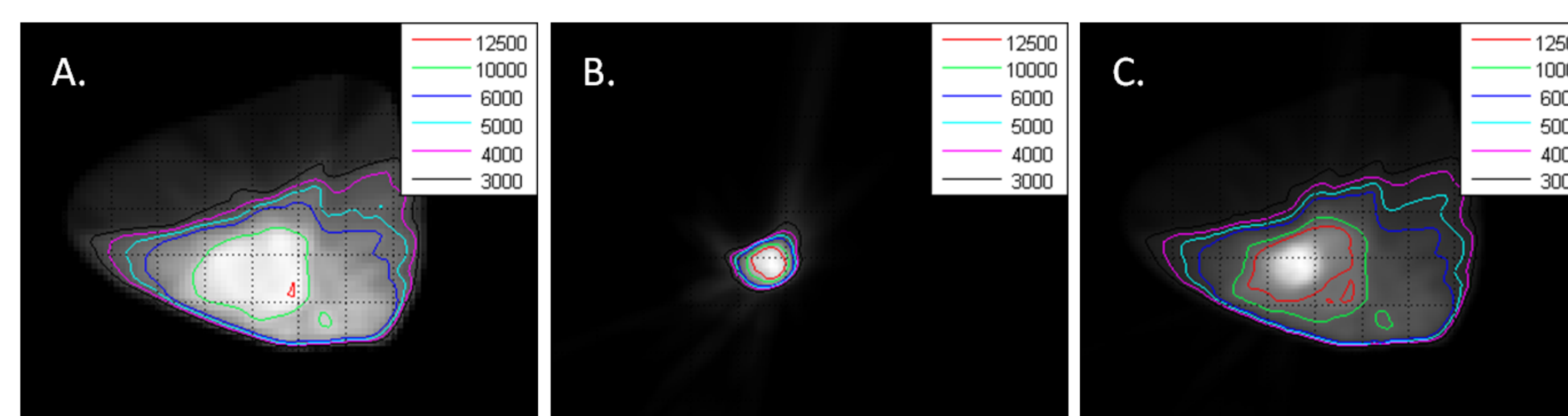


Figure 2. Representative single slices of full 3-dimensional BED distributions for small-field IMRT alone (A), SBRT alone (B) and the summation of IMRT and SBRT (C), Units are cGy_3 , 1 cm grid size.

Part 4: Future Studies/Analysis

- The cumulative BED distributions can be loaded into treatment planning systems or third party image processing software for future analysis.
- BED distributions can be visualized with the treatment planning CTs (Figure 3) for BED-based cumulative plan evaluation.
- Biological effective dose volume histograms (Figure 4) may provide an important tool for biologically based treatment plan optimization.
- Future studies will incorporate modifications to the BED formalism that better model biological response at SBRT doses.

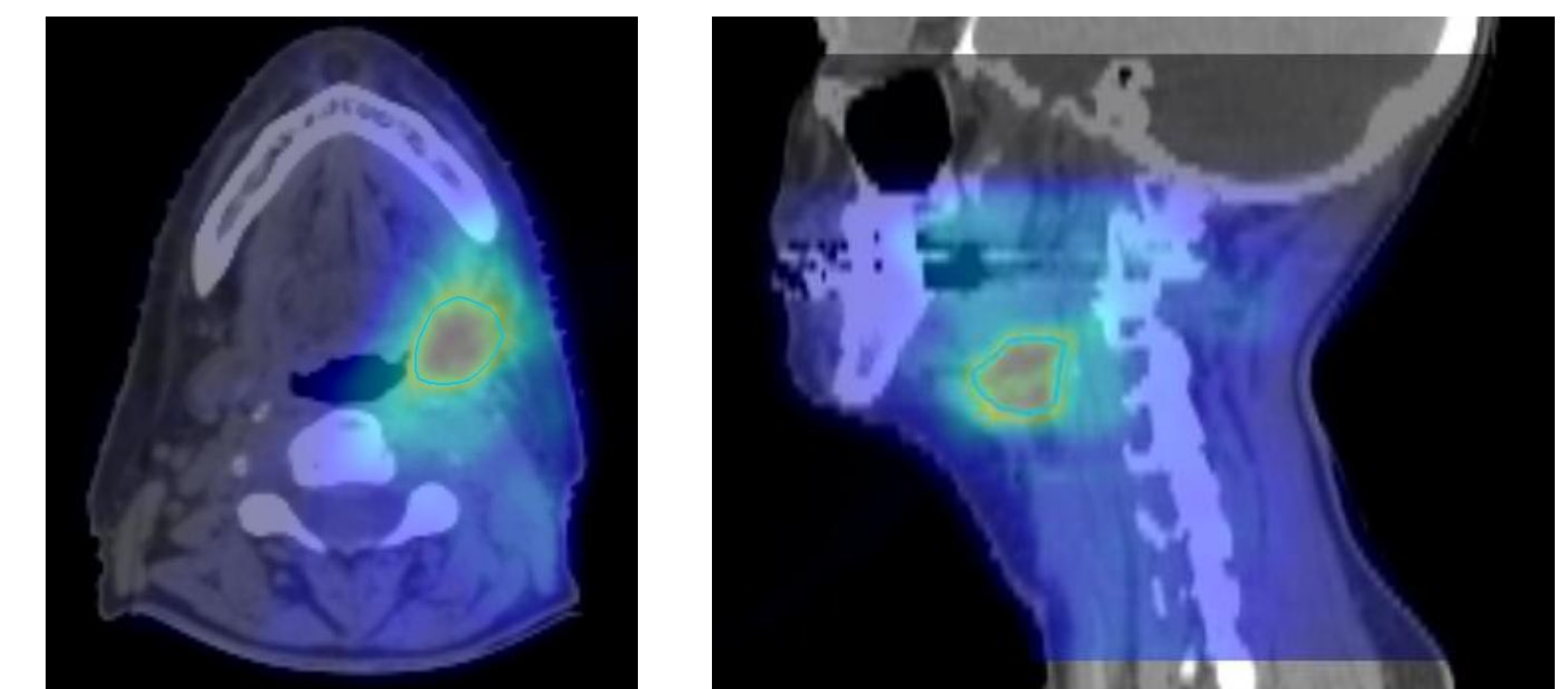


Figure 3. Cumulative BED distribution/planning CT overlay for the small-field head and neck case. Isodose line is 200 Gy_3 .

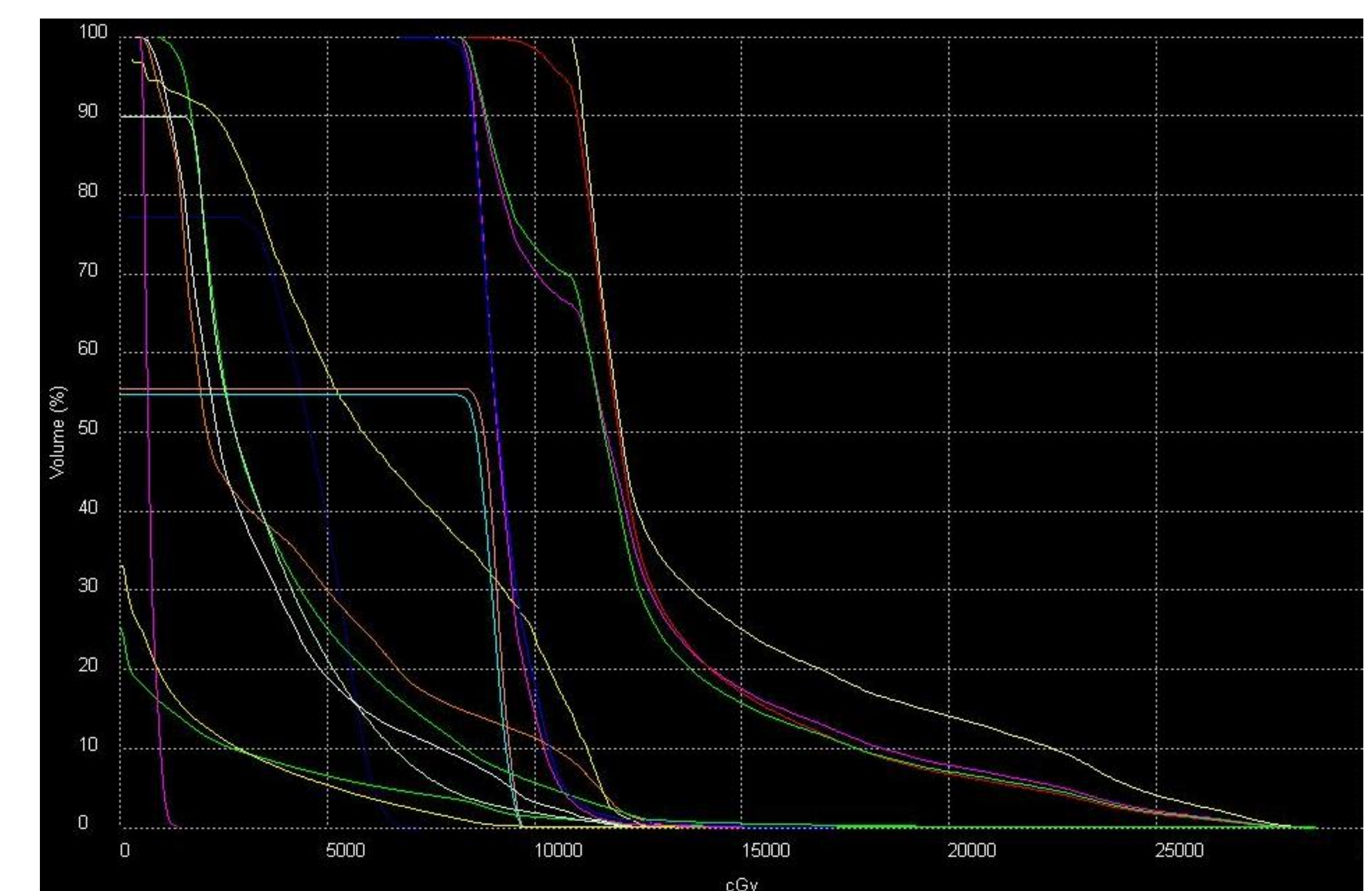


Figure 4. Cumulative biological effective dose volume histograms for the small-field head and neck case. Dose units are cGy_3 .

Conclusions

- SBRT allows for dose escalation in situations where the initial therapeutic dose is limited by the radiosensitivity of the surrounding normal tissues.
- This study provides a tool for evaluating cumulative treatment plans based in BED distributions, which is intended to augment cumulative treatment plan evaluations based on physical dose alone.
- Our initial pilot study has proven the feasibility of constructing cumulative BED distributions for patients receiving conventional radiotherapy followed by SBRT.