Dose distribution optimization for synchrotron stereotactic radiotherapy using Monte Carlo simulation

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Rationale and objectives

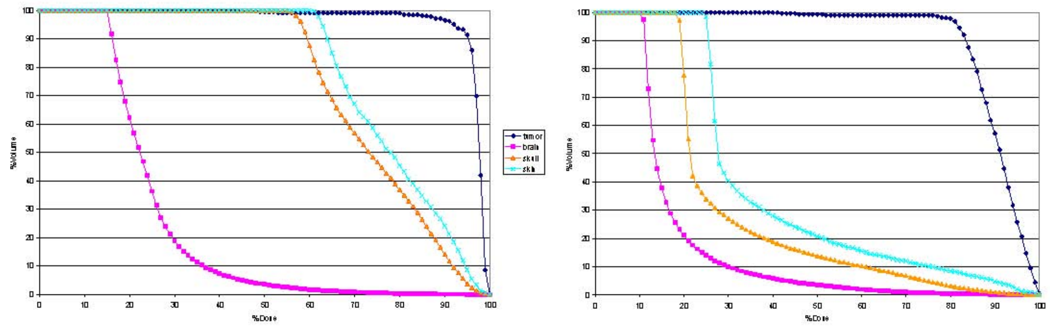
The aim of this study was to determine the most suitable combination of high-Z element and monochromatic beam energy for “heavy-element enhanced synchrotron stereotactic radiotherapy (SSRT). The dose distributions were evaluated using Monte Carlo simulations and radiation transport through a human head phantom. The performance was determine using as a figure of merit the differential effect between the dose delivered to the tumor relative to the surrounding healthy tissues. –

Methods

An analytic human head phantom (1,2) was used for our Monte Carlo dose calculation. The phantom is defined with three ellipsoids defining the skull, the brain and the tumor that is loaded with high-Z elements. The tumor (2 cm in height and 2 cm in diameter) was located either in the center of the phantom or off-centered by 4 cm. The tumor was supposed to be homogeneously filled with “tissue only” or with tissue plus 10 mg/mL of an heavy element. We evaluated three high-Z elements: iodine, gadolinium and gold. We used the general purpose Monte Carlo transport code MCNPX (version v26e) and recorded the dose using the F6 tally, in 1 mm3 voxels. The irradiations were performed with a 2*2cm2 parallel beam centered on the tumor with a continuous 360° irradiation. The dose calculations were performed in the energy range 20 keV to 120 keV, taking into account the K-edge energy of each high Z element.

Results

The dose enhancement (DEF) was defined as the average dose delivered to the tumor loaded with the high Z element relative to the average dose delivered to the tumor in absence of high Z-element. A maximal DEF of 2.4 ± 5.10-3 (at 50 keV) 2.3 ± 4.10-3 (at 60 keV), 2.28 ± 5.10-3 (at 50 keV) was obtained for I, Gd and Au, respectively. The dose delivered to various healthy organs (brain, skull and skin) were also recorded and dose volume histograms were plotted (Figure 1). In case of I-enhanced SSRT, the optimal energy for preserving the healthy brain is 60 keV. However, the use of higher energies leads to lower doses delivered to the skull.



a) tumor at the center of he head   *b) tumor with an 4cm offset*

Figure1

Dose Volume Histogramm for the tumor filled with iodine and irradiate at 90keV for the tumor centered (a) and with an offset (b).

Conclusion

The dose plan optimization is a compromise between a max DEF (from 40-60keV for all elements) and a better healthy tissue sparing effect (above 80keV). This study is a first step toward this optimization and has to be completed with a more complex irradiation geometries and heterogeneous tumors.

References

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