A treatment planning study of the clinical optimality of ion beam therapy with different ion in presence of hypoxia

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Topic category: plan comparison, outcome, hypoxia, particle therapy

Abstract

Purpose: The reduced concentration of oxygen in cells (hypoxia) results in a significantly lower cell death rate after exposure to ionizing radiation that can lead to treatment failure. This oxygen effect can be expressed by the oxygen enhancement ratio (OER) that was found experimentally to be strongly related to the quality of radiation and, in general, to the linear energy transfer (LET).

Studies to quantify this effect in treatment simulations have been pursued [1,2,3]. However, systematic studies to evaluate the impact of hypoxia in treatments with beam of different ion species are still lacking. Furthermore, the radiobiological models used to quantify the OER in these studies are based on the dose averaged LET estimates and do not explicitly distinguish among varying ion species and fractionation schemes.

In this work a new model to predict the OER taking into account the specificity of the different ions, tissues and fractionation schemes was implemented to quantify the clinical outcomes of treatments with beams of different ion species via an intercomparison of treatment plans for a set of clinical cases.

Materials and Methods: A novel model, based on the microdosimetric effect model [4], to predict the OER was implemented. The model was benchmarked with in-vitro data, V79 and HSG cells in aerobic and hypoxic conditions, irradiated with different ions [5]. The benchmarked model was then included in the simulation of treatment for set of 12 clinical cases (head and neck and prostate cancer) using p, Li, He, C and O ion beams. The plans were evaluated using a treatment planning system (TPS) that is able to evaluate the LET spectra at a voxel level for primary and secondary particles. The expected treatment optimality as a function of oxygen partial pressure, HTV size, dose per fraction and primary ion type, was quantified in terms of Tumor Control Probability (TCP) and Normal Tissue Complication Probability (NTCP).

Results: The modelized OERs were found to be dependent on both LET and ion

charge, showing also a decreasing OER for increasing dose per fraction with a slope that depends on the LET. These behaviours were found to have a good agreement with the experimental OER assays. The treatment simulations shows an substantial OER dependence by dose per fraction and an increase in TCP by increasing the ion charge and dose per fraction (e.g. up to 40% variation from p to O). However, high NTCP in normal tissue for high-LET radiation also was also observed.

Conclusions: A novel modeling of the OER that explicitly includes the dependence on ion type and dose per fraction was implemented. The model was successfully included in a TPS to evaluate the impact of hypoxia with different ion species.

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