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Calculations of the cell survival rate after irradiating with minibeams of protons and C-12

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Beams of protons and C-12 nuclei are very effective in treating deep-seated solid tumours, but collateral damage to surrounding healthy tissues is still unavoidable. It has been proposed [1], to reduce this damage by splitting a homogeneous radiation field into arrays of sub-millimetre-wide beams called minibeams. Such minibeams become wider with depth of penetration due to multiple Coulomb scattering and production of secondary particles in tissues and finally overlap in the target tumour volume [2].
In this work, the propagation of minibeams of protons and C-12 in a water phantom was simulated using the Geant4 toolkit [3] of version 10.3. Electromagnetic processes were modelled with the G4EMStandard_opt3 physics list, the Binary Cascade (BIC) model was used for proton- and neutron-induced nuclear reactions, and the Quantum Molecular Dynamics (QMD) model was used for nucleus-nucleus collisions. The modified microdosimetric kinetic model (MKM) was used to calculate the relative biological efficiency (RBE), biological dose and cell survival rate of human salivary gland (HSG) cells [4] representing tissues with normal radiosensitivity.
The hexagonal and rectangular minibeam arrays with individual beams of 0.3 mm and 0.5 mm FWHM with the centre-to-centre distance of 2 mm were considered and compared with a homogeneous radiation field. In all cases the beam energies were adjusted to obtain 60 mm wide spread-out Bragg peaks (SOBP) centered at 130 mm. A higher average cell survival rate was calculated at the entrance to the phantom and at the dose plateau for the arrays of minibeams of protons and C-12 in comparison to the homogeneous irradiation field. While a limited number of cells close to the minibeam central axes receive very high peak dose and thus inactivated, many cells between the minibeams have a high survival probability. At the same time, the cell survival rate in the target volume with minibeams was found to be similar to the survival rate in the homogeneous field. Peak-to-valley dose ratios (PVDR) and dose-volume histograms were also calculated as functions of the depth in phantom and compared for all considered minibeam irradiation geometries and homogeneous field. The calculations demonstrated the advantages of minibeams with respect to homogeneous radiation fields.

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