GOLD NANOPARTICLES IN HADRONTHERAPY: A MONTE CARLO STUDY

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Introduction: The use of gold nanoparticles (AuNPs) as a dose-boosting tool in combination with conventional radiotherapy has been discussed in the current literature. The mechanism of AuNPs radiosensitization depends on the enhanced attenuation of low-energy photons by high-Z materials through the photoelectric effect. Photoelectric absorption within gold atoms typically result in delivery of characteristic photons and Auger electron cascades. For hadrontherapy, however, the clinical benefits of AuNPs are yet to be proved. In the present work we explored the effect of AuNPs into simulated biological tissue samples during carbon ion therapy by means of Monte Carlo simulation.
Methods: This study considered a concentration of 30 mg Au/g tissue, diffuse in the treatment layer, assuming absence of gold particles outside the target. The SRIM software was used to carry out the simulations with a beam energy of 233 MeV/u (2.8 GeV). The geometry consisted in five different biological tissue layers, traversed by a perpendicular carbon beam, with the following size and densities: skin (1.2 μm - 1.09 g/cm^3), adipose tissue (1 cm - 0.92 g/cm^3), muscular tissue (3 cm - 1.04 g/cm^3), spongy skeleton (4 cm - 1.18 g/cm^3) and prostate as a target (4 cm - 1.04 g/cm^3 and 1.38 g/cm^3 with Au), summing up in a total biological tissue of 12.0012 cm depth. All those layers were selected from SRIM's compound dictionary, which contains the chemical bonding information of the compounds. Two simulations were performed, one with the presence of AuNPs (MC-AuNPs) and another without it, considering the same input configurations. The ionization and displacement damages were compared. Those calculations were made with *Kinchin-Pease* estimates. The unit of displacement damage is the number of displacements per atom (DPA). DPA is the relative measure of the lattice damage which has been created in the target material for a given total dose. The displacement damages are profoundly created at the end of the ion range which is usually located the Bragg peak.
Results and Discussions: The simulation results are shown on the Table I below:

Table I – Comparison of simulations results

Type of Simulation	Total Ionization (KeV/ion)	Max. Energy Loss (eV/Ang)	Total Displacement per ion	Longitudinal Ion Range(cm)
MC – conv.	2799493.5	13.25	5670	11.25
MC - AuNPs	2799494.7	16.32	5690	10.50

The damage rise was observed because the linear energy transfer (LET) increased with the presence of an element with high atomic number, and consequently, the ionization also increases with augmented LET of the incident ions. The ion range was 7,5 mm smaller in the MC-AuNPs. This happened since the ions loose more energy in metals with high atomic number (Z_{Au} = 79), making a shorter path throughout the tissue.
Conclusions: The present work showed an increment of the target ionization due to the interactions between the carbon ions and the internalized gold nanoparticles, resulting in a maximum energy loss of 1.23 times higher. Those interactions increased the production of low energy from secondary electrons, which, in turn, produced a significant cell damage. In other words, the addition of AuNPs may have the potential to be used as dose enhancing agent, hence rising the effect of the hadrontherapy.