Impact of using an axial magnetic field of 1.5T in carbon ion therapy for the diagnosis of head cancers.

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Abstract. To improve the irradiation accuracy in hadrontherapy, a lot of studies are in the evaluation uncluding how to integrate MRI and PET at the treatement of cancer patients. These two future techniques will offer simultaneously the monitoring of the beam during the irradiation. In this study and for the first time, we calculated the dose distribution in a voxel of the head for several carbon ion energies at B=1.5T using fluka MC code. Afterwards, either longitudinal or radial dose deflection was simulated with and without B. The maximum longitudinal deviation of bragg pick depth was 0.672 mm at 200 MeV and the the maximum radial deflection was almost 4.23 cm at 100 MeV. Both of them are in the presence of B=1.5T. Our results are in a good agreement with previous experimental results (a maximum relative error founded of 2.08%). The results of this study will offer the monitoring of the dose deposition with good accuracy in the presence of a magnetic field in carbon ion therapy.

1 Introduction

Particle therapy utilizing carbon-ion beams is a desirable cancer therapy method due to the high-dose localization and the high biological effect around the Bragg peak [1].
To treat deep tumors in a patient using carbon ions, ions have to be accelerated up to 430 MeV [2]. A speed of carbon ions at this energy is approximatively 73 % of the light speed, and a corresponding residual range in a patient is roughly 30 cm, which may cover most of tumor sites [3].
It is often difficult to completely eradicate malignant tumors in the head and neck region by surgery alone, owing to the location of these tumors or progression. Radiotherapy is, in most cases, the first-line treatment of choice for such tumors. In the head and neck region, however, various types of nonsquamous cell tumors that are not sensitive to photon radiotherapy (X- and γ-rays) develop [4]. Dose restrictions for the critical organs located in the proximity of the target lesion (e.g., the brain, brain stem, spinal cord, eyeballs, and optic nerves) limit the administration of sufficient therapeutic radiation doses. For these reasons, a considerable proportion of cases of non-squamous cell neoplasms of the head and neck region are diagnosed as intractable, resulting in poor local control rates [5].
Brain tumors, especially glioblastoma, remain the most aggressive form of all the tumors because of inefficient diagnosis and profiling [6].
The steady-state current and magnetic field are appealing features, implying simplified demands on stability, powering, mechanics and cooling, as well as for the clinical perspective, allowing rapid diagnosis.

Furthermore, for these diagnostic reasons, many numerical studies were trying to accomplish this task including the use of Monte Carlo codes.

Among that codes, fluka MC code is considered the gold standard for physical dose, especially with the last modifications which serve the implementation of dicom images which can be irradiated and dignostics in the form of voxels by using DICOM and PET tools [7].

To be more accure during the carbon ion therapy, in this study, based on Flair 2.3-0 [8,9] (FLUKA 2020.0.beta Advanced Interface), we have simulated the radial and longitudinal dose deposition of carbon ions.

Moreover, several ion energies and practical value of B (1.5T) were considered .

The fruitful results of this work will help to irradiate and monitorate the different types of head cancer with high precision [10].

2 Materials and methods

In carbon ion therapy, the use of an MC code need precise physical models capable of managing all the constituents of the expected radiation field [11].
Furthermore, the most important element of innovative research areas aimed at in vivo treatement verification is the accurate prediction of the dose deposition.
This one will focus on recent developments in the fluka MC code which is used in this study.
Fluka is a perfectly integrated Monte Carlo simulation software for particle physics [12]. It has many applications in experimental high energy and physics engineering; detector, shielding and telescope design;

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in addition to dosimetry, cosmic ray studies, radiobiology and medical physics.
In this study, using Flair (FLUKA Advanced Interface), we modeled a simple target geometry (Fig. 1) in the form of head voxel implemented by DICOM tools and surrounded by a vacuum sphere which itself is surrounded by a black hole sphere with the presence of an axial magnetic field. The dimensions of the geometry considered are given in Table 1.

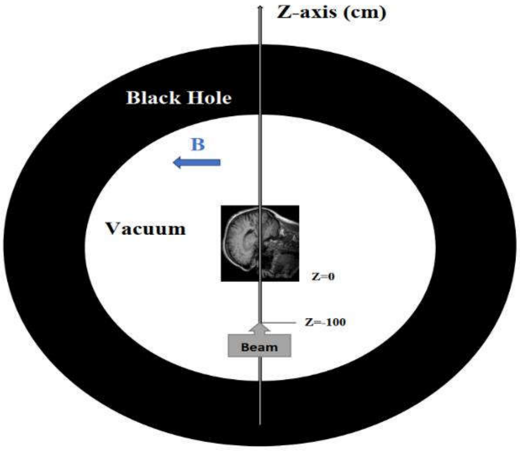

Fig. 1. Sketch of the modeled geometry (not to scale)

Table 1. The dimensions of the considered geometry

Parameters	**Numerical values (cm)**
Voxel dimension	25*25*4
Vaccum radius	100000
Black hole radius	1000000

At first; the depth relative dose was simulated in the studied voxel for a multienergetic beam ranging from 100 to 300 MeV of the carbon ions with and without B=1.5T.

Then, we recalculated this one but now for the dose deposition in GeV/g.

Afterwards, the radial and longitudinal dose deposition of carbon ion energies ranging 100-300 MeV have been simulated with and without B=1.5T.

The FLUKA simulations were performed using the recommended “HADRONTHERAPY” settings and take into account :

- inelastic form factor corrections to Compton scattering and Compton profiles.
- electromagnetic interactions, manipulated by the ElectroMagnetic FLUKA (EMF) package that administers energy loss, straggling, and multiple Coulomb scatterings of charged particles.
- low-energy neutron transport down to thermal energies.
- Entirely analog absorption for low-energy neutrons.
- particle transport threshold fixed at 100 keV, except for neutrons (10^{-5}) .
- multiple scattering threshold at minimum permitted energy, for both primary and secondary charged particles.
- rays production, with threshold 100 keV.
- hadron-nucleus interactions, described by the PEANUT model.
- The magnetic field (if B exists).

3 Results and discussion

To validate the C-ion beam simulation, the simulated Bragg pick depth at 100, 200 and 300 MeV energies are compared to the available experimental data [13] in table 2.

Table 2. A comparison between our results and the experimental ones for the studied beam.

Energy	Experimental range	Simulated range (this work)	Relative Error (RE)
100 MeV	2.59	2.5457	1.71%
200 MeV	8.74	8.5806	1.82%
300 MeV	17.37	17.008	2.08%

It is clearly shown that there exists good agreement (very low RE) between our calculations and the experimental ones in the absence of B.
In figure 2, depth relative dose distributions were calculated in the head voxel for an energy interval of carbon ions goes from 100 to 300 MeV with and without B=1.5T.
It was found that the greater the beam energy is, the deeper the maximum deposited dose is with and without B=1.5T.
Moreover, the range of the accelerated carbon ions decreases in the presence of B=1.5T.
Afterwards, the maximum depth deviation with and without B=1.5T is 0.672 mm at 200 MeV.
To compare the dose deposition with and without B, the depth dose profiles are given in figure 3 for the studied interval energy.
From this figure, we have remarked that the more the beam energy increases, the more the dose deposition decreases.

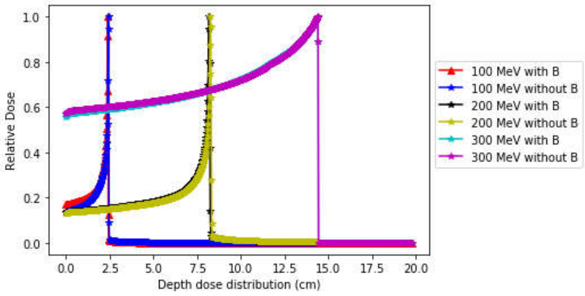

Fig. 2. Relative dose distributions for the studied beam with and without B=1.5T.

In addition to that, at a fixed energy, the dose deposition with B is higher than without it.

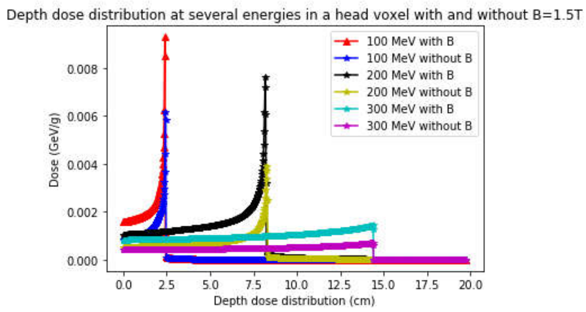

Fig. 3. Depth dose distributions for the studied beam with and without B=1.5T.

To take a fairly obvious view of the dose deflection in the head voxel taking into account the existence of B, in figure 4, we have calculated the isodoses in 2D (radial and longitudinal) with and without B=1,5T for the 3 carbon ion energies (100-200-300 MeV).

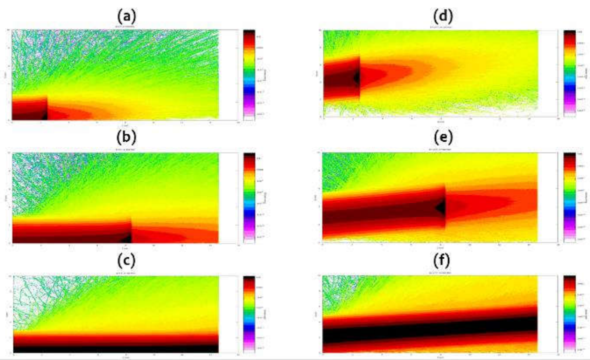

Fig. 4. (a), (b) and (c) are the isodoses for the sudied beam energies 100, 200 and 300 MeV, respectively, in the absence of B. ; (d), (e) and (f)) are the isodoses for the sudied beam energies 100, 200 and 300 MeV, respectively, in the presence of B=1.5T.

From this figure, we can easily remark the radial deflection of the dose deposition in the presence of B. We can also see that for the greater values of energy the radial deflection was tiny.

Moreover, the maximum radial deviation (in the presence of B) was at 100 MeV and it was about 4.23 cm which is very important to take it into consideration during a carbon ion therapy guided by magnetic resonance imaging.

all these deflections, whether lateral or longitudinal, are due to the force of lorentz which deflects the beam of carbon ions entering the voxel of the head (Detur effect) [14].

4 Conclusion

In summary, in this study, firstly, the relative dose distribution was calculated in a voxel of the head for several carbon ion energies and at B=1.5T using fluka MC code.

Then, after calculating the radial and longitudinal deflections of carbon ion beam in the presence of an axial magnetic field, we clearly conclude that the radial deflection was very important in comparison with the longitudinal one (a maximum deviation of 4.23 cm), which is hardly important to take it in consideration during such C ion therapy guided by MRI.

Finally, all these calculations will help to irradiate and monitorate the different types of head cancer with high precision without damaging surrounding tissue.

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