The effect of various organs in positron emitters production at proton therapy of Brain cancer; a simulation study

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Abstract
In cancer treatment with ionizing radiation, proton therapy is known as highly efficient treatment strategy due to the physical properties of protons interaction with cancer cell and normal surrounding organs considering Bragg curve concept. While protons are irradiating as therapeutic beam, positron emitters are produced on the beam path length through nuclear reactions inside patient body. In this study, a virtual head phantom with different materials has been simulated in front of Spread Out Bragg Peak of proton beam by means of Monte Carlo FLUKA code. In this simulation, the isotopes which have the most impact on positron emitters production are measured, quantitatively in proton therapy of Brain tumor. The main focus is to investigate the effects of proximal tissues along with the beam trajectory such as Skull bone on isotope producing, in a comparative fashion.

Keywords: proton therapy, brain tumor, positron emitters, Simulation, SOBP

Introduction
At recent decades, Hadron therapy is increasingly important strategy for treating deep seated tumors due to the sharp rise and fall of dose at the end of the ions range. This advantage over other radiotherapy modalities is limited in many situations by the inability to directly monitor the dose delivered to the tumor volume. The depth of the maximum dose is dependent on the beam energy, tissue composition, multiple Coulomb scattering [1], and in particular the inhomogeneities along the beam path [2–4].
Among therapeutic hadrons beams, proton therapy is increasingly gaining acceptance in cancer treatment. The power of proton therapy is that the maximum radiation dose (at the Bragg peak) will be deposited just before the end of the proton path. Beyond this point, the dose quickly falls down near zero. This characteristic enables proton beams to deliver a large radiation dose to the tumors while sparing critical distal organs. In order to achieve ideal proton treatment outcomes, an accurate calculation of tissue stopping power is needed to estimate range and proton beam dose. Despite these benefits, currently, there are many unanswered questions regarding proton therapy [5]. One of the most important unknowns is the uncertainty in the position of the Bragg peak. The exact determination of the peak position is difficult due to restriction of internal dosimetry. Therefore, in order to verifying the protons range, it is essential to have an online monitoring system out of patient body. Positron emission tomography (PET) is potentially a very useful and powerful tool for monitoring the dose distribution in proton therapy [6-8]. This method is based on the detection of 0.511 MeV photons, resulting from the annihilation of positrons emitted by positron emission radioactive decay. Positron emitters, such as ^{11}C, ^{13}N, ^{15}O are produced via non-elastic nuclear reaction of protons with the target nuclei of the irradiated tissue. After positron emitting, they move through the matter and they continually and slowly lose their energy by coulomb scattering. In this study the effect of proximal organs in isotope production has been investigated. We focused on proton therapy of brain tumor due to the presence of skull bone in front of the beam. We then compared the impact of bone with another tissue equvalent matter in a comparative fashon.

Simulation and method
The developed phantom is a kind of anthropomorphic phantom representing only head (No neck). The geometry of phantom include skin, skull bone, brain and liquid equivalent matter among brain and bone to mimic real head of adult patient. A spherical tumor located in the brain at a pre-defined depth has been taken into account as PTV irradiated with proton as therapeutic beam. All required passive modulation devices such as beam shaper and energy modulator has been defined in front of beam pathway during simulation process to deliver 3D uniform dose into target volume, using FLUKA code.
FLUKA is a validated Monte Carlo simulation package that is applicable in various fields ranging from medical physics to cosmic ray studies. In this study, proton beam

is used as Spread Out Bragg Peak (SOBP) to mimic real clinical therapeutic condition and a collimator is placed in front of the beam to act as beam shaper. In order to create the SOBP with our desired flatness treatment region (longitudinally), we developed our SOURCE.f subroutine at FLUKA simulation code. The whole phantom include some materials and surfaces similar to real patient head with a pre-defined cancer at simulation environment according to ICRU report No. 44 which is available.

Results and discussion

The simulations were performed using SOBP proton beam irradiating a soft tissue, bone, brain and tumor as PTV by using the FLUKA code. The number of protons used in each set of the simulations was five millions particles to reduce uncertainty error in an acceptable range. Simulation results include the yields (number of isotopes per unit volume per particle) of positron emitter nuclei per beam particles in beam direction for four different materials of head as listed at Table 1. As shown, few ^{15}O isotopes are created in brain, resulting few interaction with brain atmos nuclei.

The results in Table 1, for soft tissue, bone and cancer, display that the yields of ^{15}O,^{11}C and ^{13}N are ordered and the yields are increased by the elements of target. However,^{11}C has the highest yield instead of ^{15}O. This is due to the difference between cross sections at these types of materials. As next step, the bone of skull was replace with water euqivalent matter and the simulation was repeated with same parameters. By this way the effect of skull bone can be investigated in a comparative fashion. The final comparison results was shown at table 2.

Tables

Table 1. calculated yield of positron-emitting nuclei (per beam particle) produced by proton SOBP beam in soft tissue, head bone, brain and tumor.

Positron emitter	Rigens: Soft tissu	Head bone	Brain	Cancer
^{15}O	0.000265 ±1.9%	0.00022 ±3.5%	0.0000002 ±3%	0.00000021 ±4.1%
^{14}O	0.0000053 ±2.5%	0.000026 ±3.1%	0	0.00000009 ±2.8%
^{11}C	0.000091 ±2.7%	0.00012 ±3.3%	0	0.0000098 ±2.4%
^{10}C	0.000006 ±1.7%	0.000003 ±2.2%	0	0.00000015 ±3.3%
^{13}N	0.000024 ±3.9%	0.00014 ±2.8%	0	0.000061 ±1.1%

Table 2. calculated yield of positron-emitting nuclei (per beam particle) produced by proton SOBP beam in soft tissue, brain, tumor and for estimating bone impact, this rigen is replaced with water

Positron emitter	Rigens: Soft tissu	Replaced head bone with water	Brain	Cancer
^{15}O	0.0001676 ±2.8%	0.000108 ±3.4%	0	0
^{14}O	0.0000086 ±4.1%	0	0	0.000001 ±4.6%
^{11}C	0.0000536 ±2.1%	0	0	0.000012 ±2.4%
^{10}C	0.0000016 ±3.9%	0	0	0.0000003 ±4.4%
^{13}N	0.000038 ±3.3%	0.000165 ±3.5%	0	0.0000673 ±2.9%

Conclusions

This work consists of a quantitative assessment on positron emitters production during proton therapy of Brain cancer. The main aim was investigating on impact of the Skull base as bone and soft tissue in front on the therapeutic beam on positron emitters generation. As shown, the most important nuclei is Oxygen-15 as positron emitter. It should be noted that the energy of protons and the tumor site inside the brain have the important roles for positron emitters nuclei. Moreover, generating of isotopes in brain in both simulation displays that the SOBP beam had an exact impact on the tumor site.

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