Available online at www.sciencedirect.com

ScienceDirect

journal homepage: http://www.elsevier.com/locate/rpor

Original research article

Evaluation of energy deposition and secondary particle production in proton therapy of brain using a slab head phantom

Sayyed Bijan Jia[a,1], *Mohammad Hadi Hadizadeh*[a,1], *Ali Asghar Mowlavi*[b,*], *Mahdy Ebrahimi Loushab*[a,1]

[a] *Physics Department, School of Sciences, Ferdowsi University of Mashhad, P.O. Box 91775-1436, Mashhad, Iran*
[b] *Physics Department, School of Sciences, Hakim Sabzevari University, P.O. Box 397, Sabzevar, Iran*

ARTICLE INFO

Article history:
Received 14 May 2013
Received in revised form
24 March 2014
Accepted 7 April 2014

Keywords:
Proton therapy
Slab head phantom
Bragg peak
Energy deposition
Secondary particle production

ABSTRACT

Aim: Evaluation of energy deposition of protons in human brain and calculation of the secondary neutrons and photons produced by protons in proton therapy.
Background: Radiation therapy is one of the main methods of treating localized cancer tumors. The use of high energy proton beam in radiotherapy was proposed almost 60 years ago. In recent years, there has been a revival of interest in this subject in the context of radiation therapy. High energy protons suffer little angular deflection and have a well-defined penetration range, with a sharp increase in the energy loss at the end of their trajectories, namely the Bragg peak.
Materials and methods: A slab head phantom was used for the purpose of simulating proton therapy in brain tissue. In this study simulation was carried out using the Monte Carlo MCNPX code.
Results: By using mono energetic proton pencil beams, energy depositions in tissues, especially inside the brain, as well as estimating the neutron and photon production as a result of proton interactions in the body, together with their energy spectra, were calculated or obtained. The amount of energy escaped from the head by secondary neutrons and photons was determined.
Conclusions: It was found that for high energy proton beams the amount of escaped energy by neutrons is almost 10 times larger than that by photons. We estimated that at 110 MeV beam energy, the overall proton energy "leaked" from the head by secondary photons and neutrons to be around 1%.

* *Corresponding author*. Tel.: +98 571 4411161; fax: +98 571 4411161.
E-mail addresses: bijan.Jia@stu-mail.um.ac.ir (S.B. Jia), mhhadi@ferdowsi.um.ac.ir (M.H. Hadizadeh), amowlavi@sttu.ac.ir, aa_mowlavi@yahoo.com, amowlavi@hsu.ac.ir (A.A. Mowlavi), ebrahimi.mahdy@gmail.com (M.E. Loushab).
[1] Tel.: +98 511 879 7022.
http://dx.doi.org/10.1016/j.rpor.2014.04.008

1. Background

Nowadays, radiation therapy is one of the three main methods of treating localized cancer tumors. Photons are the most common type of particles in radiotherapy.[1] Despite major technical developments,[2] the exponential decrease in the number of primary photons remains the main problem due to the nature of photon interactions in matter. Thus, photons have no well-defined range and their dose profiles diminish exponentially. So, a considerable dose is received by healthy organs, before and after the tumor. Unlike photons, charged particles have relatively well-defined penetration range. The dominant mechanism by which charged particles lose their energies is inelastic interaction with the atomic electrons. They lose most of their energies near the end of their paths, at the so called Bragg peak.[3,4]

Beside coulomb interaction with atomic electrons and elastic nuclear scattering, protons moving inside the matter undergo inelastic nuclear interactions in which secondary particles, such as neutrons, photons, secondary protons, deuterons, are produced.[3] In the energy range used for proton therapy, neutrons and photons are the most important secondary particles, in a sense that they can travel far distances from the target tissue and store their energies in other organs, thereby increasing the risk of secondary cancers.[5,6]

Secondary particles in hadron therapy have two different origins:

- First, those produced in the delivery system placed before particles enter the body. These can mostly be avoided by proper shielding.
- Second, those produced inside the body itself due to the interactions of incident particles with the body tissues, which cannot be eliminated with mechanical techniques. Therefore, their flux and energy deposition have to be calculated in order to estimate the risk of secondary cancers.

Quite numerous studies, with both Monte Carlo (MC) and experimental methods, have dealt with this issue.[6–10] Measured neutron doses from clinical proton facilities vary greatly, partly as a result of different measurement techniques, and partly as a result of different beam geometries.[11]

Kim et al.[12] compared secondary radiation doses from IMRT and proton beam therapy for lung and liver cancers using ion chamber and CR-39 detectors. They declared that the secondary dose per treatment Gy for proton beam therapy ranges from 0.17 to 0.086 mGy at 20–50 cm from the isocenter, whereas, it ranges from 5.8 to 1.0 mGy for IMRT. The internal neutron dose is much lower, ranging from 0.03 to 0.008 mGy. The dose due to the secondary neutrons and photons was estimated with Monte Carlo simulation for three existing proton therapy facilities by Agosteo et al.[10] They indicated that the dose from secondary particle for passive systems is 10 times higher than that for active systems. Paganetti et al.[6] used the Geant4 toolkit to simulate the proton beam line at MGH proton therapy center in order to estimate neutron doses to organs which are out-of-field. They divided the neutron dose into internal part, due to proton interactions in the body, and external part, due to proton interactions with components of the delivery system. Brenner and Hall[11] estimated neutron equivalent doses to relevant organs, based on the neutron doses reported by Paganetti et al., considering a conservative estimate of 25 for low-dose RBE. Then, they used these organ-specific equivalent doses to calculate lifetime cancer risks, using standard techniques which were described in the US National Academy of sciences BIER-VII report, and other radiation risk reports.[13–15] They estimated the overall lifetime cancer risk for a 15-year-old boy at about 4.7% and for a 15-year-old girl at about 11.1%. They indicated it to be larger for a younger patient and smaller for an older patient.

2. Aim

In this study we evaluated the energy deposition of the proton beam in the human brain phantom, and calculated the secondary neutrons and photons produced by protons. A good knowledge on pristine depth and lateral dose profiles in the target volume is necessary to choose a reasonable beam displacement to have a good conformation with the shape of the tumor, and spare the normal tissues.[16] Traditionally, dose calculations and TPS (treatment planning systems) in hadron therapy are, mostly, done in water[17] due to its proximity to soft tissues. To be more precise, it would be better to take into account the exact composition and sequence of different tissues.[18] This, indeed, is the main task of this work.

3. Materials and methods

3.1. Head phantom

The simplified head phantom was modeled. The tissue properties, from up to down, in vertical direction are 0.2 cm human skin, 0.3 cm soft tissue, 0.9 cm cranium, 11.5 cm brain, 0.9 cm cranium, and, finally, 0.5 cm soft tissue as presented in Fig. 1. Mass densities and compositions of the organs are given in Table 1.[19]

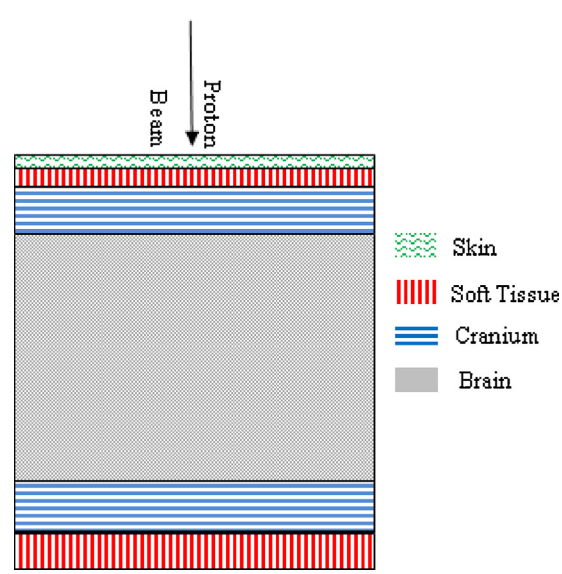

Fig. 1 – Geometry of the slab head phantom.