Transactions of the Korean Nuclear Society Autumn Meeting
Goyang, Korea, October 24-25, 2019

Optimization for Noninvasive Cardiac Radiation Therapy Aimed at Ablation Ventricular

Kilyoung Ko [a], Wooseub Kim [a], Minju Lee [a], Jisung Hwang [a], Junhyuk Kim [a], Gyusung Cho [a*]
[a]*Dept of Nuclear & Quantum Engineering, Korea Advanced Institute of Science and Technology., Daejeon 291*
[*]*Corresponding author: gscho@kaist.ac.kr*

1. Introduction

Latterly, noninvasive cardiac tissue ablation to control arrhythmia has been pioneering a new path as a therapeutic method. Furthermore stereotactic body radiation therapy (SBRT) has been successfully performed in patients suffering from ventricular tachycardia [1]. The SBRT commonly uses photon, proton, and heavier ion than proton. The proton and heavier ion are charged particles that have got a specific physical characteristic, so-called Bragg peak. Bragg peak refers to sharp energy fall-off at the end of particle range and this allows a high energy concentration to the treatment target area [2]. High energy concentration demonstrates a high radiation dose that enables cell killing effectively compared to electromagnetic radiation [3]. As a result of this energy delivering, irradiated tissue will undergo apoptosis after a few months and the treatment effect based on cell fibrosis, a byproduct of apoptosis, will occur. The introduction of this treatment, currently undergoing clinical trials, is considered to require an optimization process within a complex anatomical environment, human chest, for enhancing accuracy of treatment [4].

For this purpose, this research conducted an anatomical structure description for simulation and ion beam optimization study using Monte-Carlo simulation.

2. Material and Methods

This paper aims at the characteristic evaluation of the ion beam with a change of ion, energy range, and medium. To this end, first, proton and carbon ion were adopted as incidence particles for simulation. Second, energy ranges of proton and carbon are 100-150 MeV/nucleon and 100-300 MeV/nucleon, respectively to observe changes in properties depending on energy. Third, a characteristic evaluation was carried out in various medium present in the thorax. Finally, the energy transfer rate to the target point according to the energy of the ion beam was compared.

2.1 Anatomical structure description

One of the most complex parts of the body is the chest. The chest part has various organs inside the ribs that support the structure, and unlike other parts, relatively large cavity can exist depending on incidence direction of beam. This will be an element that could be an obstacle in shaping the treatment plan. In this study, the structure for the simulation process will be constructed from anatomical information based on describing the cross-sectional area. The thickness of each tissue through which the particles pass may differ, but will commonly enter the target area through skin, mediastinum, pericardial cavity, and heart wall [5].

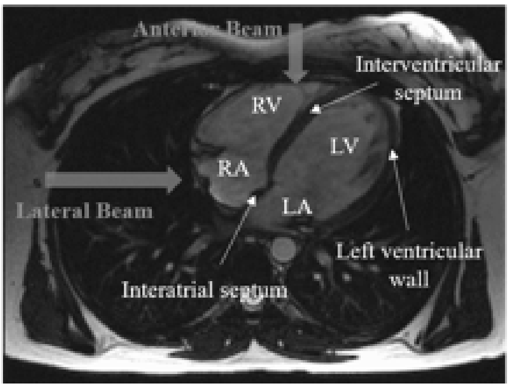

Fig. 1. Depth difference depending on incidence direction of beam and cardiac structure in chest computed tomography image

In the optimization process, the behavior of particles will be evaluated based on information based on the organ materials. The material for each organ was used computed phantom data of the International Commission on Radiological Protection (ICRP) to properly adopt simulation.

Table I: Material composition of organ Tissue

Elements	Composition		
	Lung *(0.386 g/cm³)*	Heart Wall *(1.05 g/cm³)*	Residual *(0.95 g/cm³)*
Hydrogen	0.103	0.104	0.114
Carbon	0.107	0.138	0.588
Nitrogen	0.032	0.029	0.008
Oxygen	0.746	0.719	0.287
Sodium	0.002	0.001	0.001
Phosphorus	0.002	0.002	0.001
Sulfur	0.003	0.002	0.000
Chlorine	0.003	0.002	0.001
Potassium	0.002	0.003	0.000

2.2 Simulation tools

In this study, optimization for noninvasive cardiac radiation therapy is performed with Monte Carlo simulation. MCNP6 1.0 was used for Monte Carlo simulation to evaluate particle transport. MCNP has been widely used for many years now in nuclear engineering to perform medical physics simulation, radiation protection and dosimetry, and radiography. Various results on V&V of the Cascade-Exciton Model, 2013 (CEM) as implemented in the code CEM03.03 was used at present as the option of MCNP6 to simulate reactions [6]. Proton and carbon ion were adopted as incidence particles for simulation. The energy range of protons and carbon ions is 100-150 MeV/nucleon and 100-300 MeV/nucleon, respectively.

3. Result and Discussion

The energy accumulation from a single particle was calculated by dividing each organ by 100 μ m apart. A total of 2000 sections were created to observe the behavior of particles up to a depth of 200 mm. As a result of this assessment, it was possible to verify the change in the depth of incidence of the Bragg peak depending on the energy of the particles.

The energy transfer of a single particle to the target point shows that carbon ions were far superior to protons. Also, by forming a sharper peak, the effect on normal cells can be minimized to increase the likelihood of precise treatment. However, the results show a rapid decrease in energy transfer at the end of range, target point, although their permeability increases with energy. As shown in Figure 4, it can be seen that the change of medium has a significant effect on the behavior of particles with carbon ions of the same energy. This means that the beam direction that passes through various mediums make difficult to perform the precise clinical treatment.

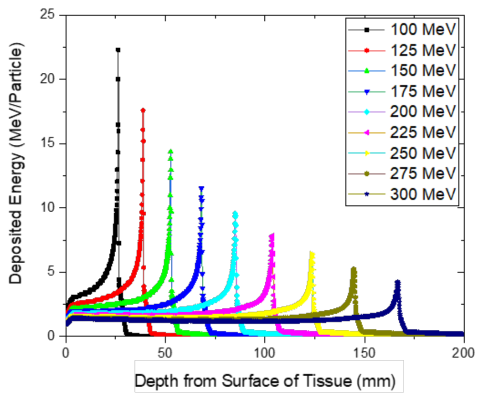

Fig. 2. Bragg peak depth distribution depending on carbon

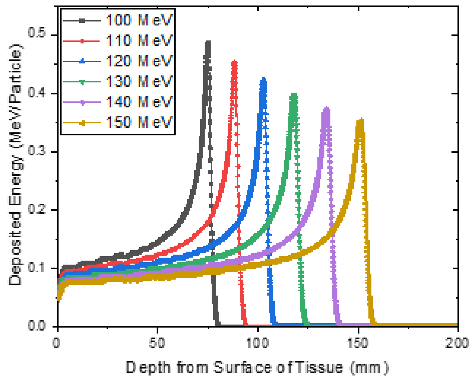

Fig. 3. Bragg peak depth distribution depending on proton

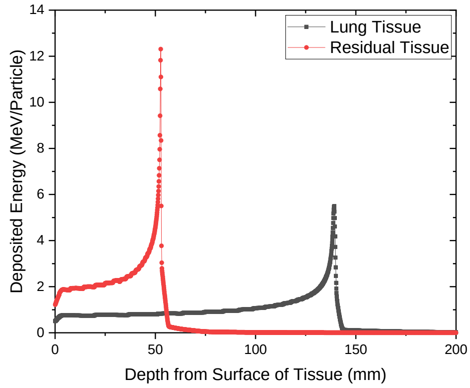

Fig. 4. Difference of Bragg peak depth distribution of carbon ion depending on medium

As shown in Table 2, as the energy of particles increases the total amount of energy transferred to the human body increases, but the energy to the target decreases. This suggests that the basis of optimization is to minimize the distance of the target from the surface to use particles with relatively low energy to perform the efficient treatment

Table 2: Energy transfer from single particle

Carbon ion energy	Energy transfer from single particle		
	Total transferred energy (MeV/g)	Target transferred energy (MeV/g)	Ratio (%)
100 MeV	107.16	38.82	36.23
125 MeV	124.91	33.98	27.21
150 MeV	141.51	31.53	22.28
175 MeV	156.61	28.49	18.19
200 MeV	169.51	25.12	14.82
225 MeV	180.08	22.70	12.60
250 MeV	187.97	19.34	10.29
275 MeV	193.06	16.53	8.56
300 MeV	195.03	14.33	7.35

Through the induction of trend lines using simulated data, the depth of the Bragg peak was estimated according to energy. For ease of comparison, the experimental range was determined as the depth of the zenith of the Bragg peak. The data from International Commission on Radiation Units and Measurements (ICRU) Report 73 was utilized as a control group for the estimated values, and the comparison results in an average error rate of less than 2.4 %.

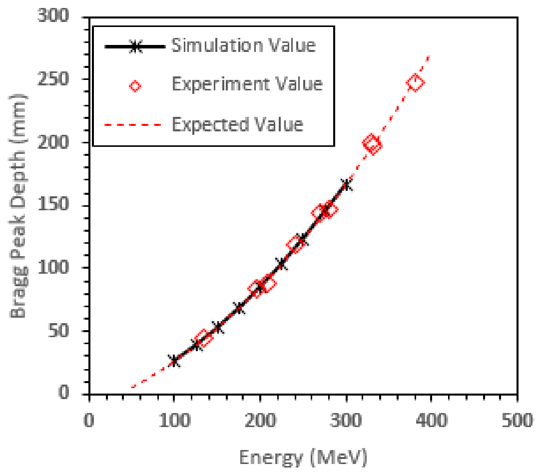

Fig. 5. The trend line of simulation data and experimental data for verification

4. Conclusion

This research conducted an optimization study for noninvasive cardiac radiation Therapy aimed at ablation ventricular. As a result of the study, the properties of protons and heavy ions were evaluated using the MCNP code. It was also possible to discover deeper permeation and relatively less energy transfer in relatively less dense lung tissue. In addition, we have found that as the energy of the particles used increases, the energy delivered as whole increases, but the amount of energy reaching the target decreases. This means that establishing a treatment plan by setting the shortest distance to the target in performing this treatment is an optimized method. This research will provide a good means of drawing a potential insight into treatment planning and ion beam simulation process.

ACKNOWLEDGEMENT

This work was supported by the Nuclear Research & Development Program of the National Research Foundation of Korea grant funded by the Ministry of Science, ICT and Future Planning under Grant 2017M2A2A6A02020807, 2018M2A8A5023361. This work was partly supported by a National Research Foundation of Korea grant funded by the Korean government under Grant NRF-2017M2A8A5015084.

REFERENCES

[1] P. S. Cuculich et al., “Noninvasive Cardiac Radiation for Ablation of Ventricular Tachycardia,” N. Engl. J. Med., 2017.
[2] D. R. Grimes, D. R. Warren, and M. Partridge, “An approximate analytical solution of the Bethe equation for charged particles in the radiotherapeutic energy range,” Sci. Rep., 2017
[3] H. I. Lehmann et al., “Feasibility Study on Cardiac Arrhythmia Ablation Using High-Energy Heavy Ion Beams,” Sci. Rep., 2016.
[4] F. Rapp et al., “Biological Cardiac Tissue Effects of High-Energy Heavy Ions – Investigation for Myocardial Ablation,” Sci. Rep., 2019.
[5] C. E. Lipscomb, “Medical Subject Headings (MeSH).,” Bull. Med. Libr. Assoc., 2000.
[6] Monte Carlo Team, “MCNP - A General Monte Carlo N-Particle Transport Code, Version 5,” Los Alamos Nucl. Lab., 2005.