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Determination of Proton Energy and Dosage to Obtain SOBP Curve in the Proton Beam Radiotherapy Treatment Planning

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ABSTRACT
In this research, calculations and simulations to obtain SOBP curve on the model of the thyroid tumor were done by determining the energy and the number of protons in each beam of protons. Simulations carried out with the help of the SRIM and TRIM code, while the computational calculations and graphics were done with python. The SOBP curve profile obtained from this study is flatter in the region of the tumor compared to previous results by other researchers, and can be concluded that tumor tissue receives a uniform lethal dose, while other normal tissues surrounding receive non-lethal doses. Quantitatively, if the dose received by the tumor tissue is expressed as 100% dose, the dose received by healthy tissue outside the tumor is a maximum of 92%.In a further development, this research method can be applied to other tissue model based on the image of the CT-SCAN containing tumor tissue.
Keywords: proton beam radiotherapy, Bragg curve, TRIM, SRIM, SOBP

I. INTRODUCTION

Proton beam radiation therapy has been conducted for 60 years and is still growing today. Methods and new techniques are still being studied to obtain optimal therapeutic results, which provide a lethal effect on tumor tissue but safe for the surrounding healthy tissue. Development of methods in our study is how to obtain the dose profile named SOBP (Spread Out Bragg Peak). The SOBP curve is a profile which is a requisite dose of radiotherapy using charged particles, a condition which is the radiotherapy dose is high and flat in the area of the tumor, and lower in areas outside the tumor [1].In general, the dose distribution is calculated using commercial equipment radiotherapy planning based on analytic algorithm-pencil beam[2][3][4][5].

Several researchers have conducted studies to determine SOBP curves in different ways (methods)[6][7][8][9]. Some researchers have proposed analytical equation and the other using simulation methods. The SOBP curves obtained are still not as expected.

II. METHODS AND MATERIALS

Tumor model used are like those used by Mowlavi et al [10] as shown in Figure 1. The composition of the constituent tissues in the model, as well as the thickness of each tissue, are presented in Table 1. The proton energy must be determined in order to ensure that the proton stop at the tumor tissue. The equation used to calculate the energy E that proton will stops at a certain range R is

$$E = e^{a + b\ln(R)} \quad \text{(MeV)} \qquad (1)$$

a and b are parameters whose value depends on the model being investigated. We found that the value of a is 2.234 and the value of b is 0.552. The equation was obtained by the curve fitting method to the proton energy and range data values produced by SRIM code.

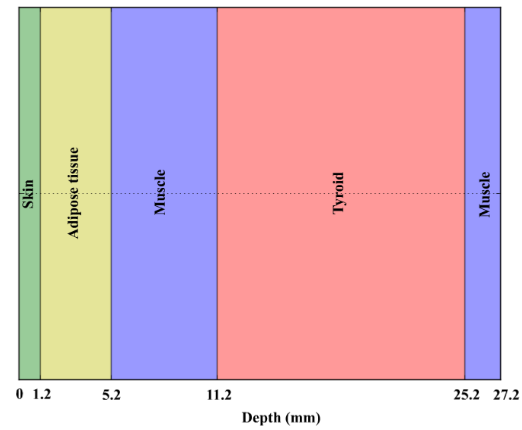

Figure 1. The model of thyroid tumor

The tumor tissue area is divided into 28 layers with thickness of 0.5 mm. Each layer is the location that each proton beam has to stop. The proton energy in each beam is calculated using (1) and the results are presented in Table 2.

Table 1. Tissue type, width and composition [10]

Tissue	Width (mm)	Density (gm/cm^3)	Composition
Skin (type 3)	1,2	1,09	H,C,N,O,Na, S,Cl,K
Adipose	4	0,92	H,C,N,O,S,

tissue			Cl, P, Mg
Muscle (type 2)	6	1,05	H,C,N,O,S, Cl,K,P
Thyroid	14	1,05	H,C,N,O,Na, Cl,K
Muscle (type 1)	2	1,05	H,C,N,O,S, Cl,K,P

Table 2. Proton energy in each beam

No	Range (mm)	Energy (MeV)
1	24.70	54.825
2	24.20	54.210
3	23.70	53.589
4	23.20	52.962
5	22.70	52.329
6	22.20	51.689
7	21.70	51.043
8	21.20	50.391
9	20.70	49.731
10	20.20	49.065
11	19.70	48.390
12	19.20	47.709
13	18.70	47.019
14	18.20	46.321
15	17.70	45.614
16	17.20	44.898
17	16.70	44.173
18	16.20	43.438
19	15.70	42.692
20	15.20	41.936
21	14.70	41.169
22	14.20	40.390
23	13.70	39.599
24	13.20	38.795
25	12.70	37.976
26	12.20	37.144
27	11.70	36.295
28	11.20	35.431

A total of 28 protons with different energies are then simulated by TRIM to obtain ionization curve, which is the Bragg curve. SOBP curve is the sum of all 28 of the Bragg curve. If the 28 Bragg curve indicated by the symbol y_1 to y_{28}, and the SOBP curve indicated by the symbol y_m, then relationship between Bragg curve with SOBP curve can be written as

$$y_m = A_1 y_1 + A_2 y_2 + A_3 y_3 + \cdots + A_{28} y_{28} \quad (2)$$

A_1 to A_{28} is the weighting factor that must be found in order to form SOBP curve as expected, that is a maximum flat on the region of the tumor, and lower in areas outside the tumor. The weighting factors are then used to determine the number of protons in each beam. If the total count of protons required is N, the number of protons in each beam is calculated using:

$$N_i = \frac{A_i}{\sum_i A_i} N \qquad (3)$$

III. DISCUSSION

Figure 2 shows the results of simulations of 500 protons with TRIM. The greater the number of protons, the smoother the resulting curve because the curve obtained from the TRIM simulation is an average value for the entire proton which has been simulated. The upper curve is SOBP curve which is obtained by adding curves beneath whose value is $A_i y_i$ (i=1,…,28).

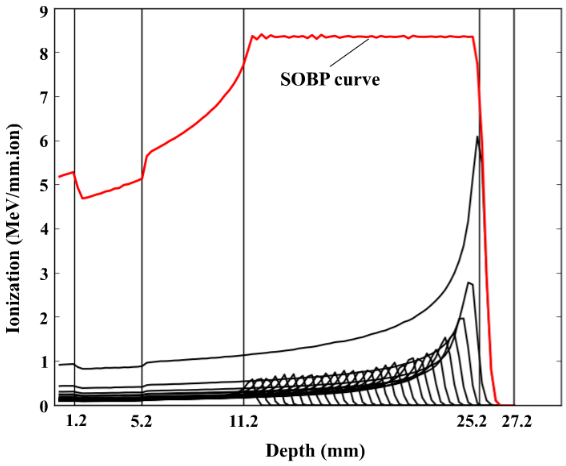

Figure 2. SOBP curve obtained from the simulation of 500 protons with TRIM

The number of protons is correlated with the dose required for therapy. For example, for a dose of 2 Gy, the number of protons required are as many as 7.2×10^{10} protons. The dose or the number of protons for each beam of protons is calculated using equation (3), and the results are presented in Table 3. In practice, the proton beam used in radiotherapy is expressed as electrical current, then the number of the proton is determined by adjusting the duration of proton current for each proton beam.

Table 3. Range, energy, and number of proton in each beam

No.	R_i (mm)	E_i (MeV)	A_i	N_i
1	24.70	54.825	0.783719	1.53E+10
2	24.20	54.210	0.299590	5.84E+09
3	23.70	53.589	0.240332	4.69E+09
4	23.20	52.962	0.189086	3.69E+09
5	22.70	52.329	0.168528	3.29E+09
6	22.20	51.689	0.148590	2.90E+09
7	21.70	51.043	0.135579	2.64E+09
8	21.20	50.391	0.124406	2.43E+09

9	20.70	49.731	0.116851	2.28E+09
10	20.20	49.065	0.108274	2.11E+09
11	19.70	48.390	0.103765	2.02E+09
12	19.20	47.709	0.096799	1.89E+09
13	18.70	47.019	0.094036	1.83E+09
14	18.20	46.321	0.090223	1.76E+09
15	17.70	45.614	0.085510	1.67E+09
16	17.20	44.898	0.082923	1.62E+09
17	16.70	44.173	0.080327	1.57E+09
18	16.20	43.438	0.076659	1.49E+09
19	15.70	42.692	0.076450	1.49E+09
20	15.20	41.936	0.072195	1.41E+09
21	14.70	41.169	0.071663	1.40E+09
22	14.20	40.390	0.068888	1.34E+09
23	13.70	39.599	0.067918	1.32E+09
24	13.20	38.795	0.064864	1.26E+09
25	12.70	37.976	0.064503	1.26E+09
26	12.20	37.144	0.062958	1.23E+09
27	11.70	36.295	0.062734	1.22E+09
28	11.20	35.431	0.055998	1.09E+09

Table 4 shows the dose received by each normal tissue compared with the dose received by the tumor tissue obtained from SOBP curve. So if the tumor tissue receives a minimal dose that can kill tumor cells, then the other tissue which received lower doses will remain safe

Table 4. Percentage dose received by tissues

Layer	**Tissue**	**Dose received**
1	Skin	min. 62%, max. 63%
2	Adipose	min. 56%, max. 62%
3	Muscle	min. 62%, max. 92%
4	Tyiroid	100%
5	Muscle	min. 0%, max. 86%

IV. CONCLUSIONS

The results show that the proposed method can produce a desired SOBP curve, but it still need to be tested clinically. The same method can be applied to other models of tumor tissues obtained from the CT-SCAN or another imaging method.

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