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Stopping power and range calculations of protons in human tissues

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Abstract:

In this research, the stopping power and range of protons in biological human soft and hard tissues (blood, brain, skeleton-cortical bone, and skin) of both child and adult are calculated at the energies ranging from 1MeV to 350 MeV. The data is collected from ICRU Report 46 and calculated the stopping power employing the Bethe formula. Moreover, the simple integration (continuous slowing down approximation) method is employed for calculating protons range at the target. Then, the stopping power and range of protons value in human tissues have been compared with the program called SRIM. Moreover, the results of the stopping power vs energy and the range vs energy have been presented graphically. Proper agreement is found between the gained and the SRIM results and varies almost linearly with energy up to 250 MeV.

Key words: Human tissue, Proton, Range, SRIM, Stopping power.

Introduction:

In recent years, the theoretical and experimental studies of the stopping power (SP) and range of charged particles have been increasing immensely in radiation physics. Many theoretical, as well as experimental studies have been established on this topic quite efficiently. The calculation of stopping power and range of protons plays an important role in proton and cancer therapy (1). Hence, precise knowledge of SP and range of protons are needed for the exact dosimetry of proton radiation (2-4). When studying the SP and range of protons in a biological target, one must determine or collect data from experimentally or ICRU report. Scientists are working on the SP and range of protons in human tissues (skin, bone, blood, kidney, liver, brain, breast, etc.) in order to improve proton therapy in medical physics (5).

The composition of the human body gradually changes as the child becomes adult until the associate organs mature completely (6). As the body growth begins, the water content starts to decrease from fetal tissues while the lipid and protein contents increase. The mass and densities of the human body are made up of some basic elements like hydrogen, carbon, oxygen, nitrogen, etc. and these elemental compositions vary from bone to bone, body to body, and age to age (6). The prime concern in this study is selecting some body tissues with different ages to get the difference in values in the same body tissues. The values of SP and range can vary depending on the difference in the composition of targets (7). The aim of this study is to get the difference in results that can be beneficial for clinically relevant work like proton therapy.

In this study, the elemental compositions data of some human tissues (blood, brain, skeleton-cortical bone, and skin) of both child and adult is collected and that is given below in Table 1. The Bethe formula is implemented for the theoretical calculations of the protons SP at clinically relevant proton energies ranging from 1 MeV to 350 MeV (8). And the Continuous Slowing Down Approximation (CSDA) method is used for protons range calculations in the targets (9). Then the SP and CSDA range values are tabulated and compared them with the SRIM data. Finally, the results of our study and SRIM are presented graphically so that interested readers can simply understand the abbreviation of the paper.

Table 1. The elemental compositions and mass densities of some human body tissues (6).

Tissues	Elemental composition (percentage by mass)					
	H	C	N	O	Others	ρ(g/cm^3)
Blood (child)	10.0	13.1	4.0	72.0	0.1 Na, 0.1 P, 0.2 S, 0.2 Cl, 0.2 K, 0.1 Fe	1.07
Blood (adult)	10.2	11.0	3.3	74.5	0.1 Na, 0.1 P, 0.2 S, 0.3 Cl, 0.2 K, 0.1 Fe	1.06
Brain (child)	10.7	9.1	1.6	77.6	0.2 Na, 0.3 P, 0.1 S, 0.2 Cl, 0.2 K	1.03
Brain (adult)	10.7	14.5	2.2	71.2	0.2 Na, 0.4 P, 0.2 S, 0.3 Cl, 0.3 K	1.04
Skeleton-cortical bone (child)	3.8	16.0	4.4	44.3	0.1 Na, 0.2 Mg, 9.9 P, 0.3 S, 21.0 Ca	1.83
Skeleton-cortical bone (adult)	3.4	15.5	4.2	43.5	0.1 Na, 0.2 Mg, 10.3 P, 0.3 S, 22.5 Ca	1.92
Skin (child)	10.4	10.4	2.8	75.5	0.2 Na, 0.1 P, 0.2 S, 0.3 Cl, 0.1 K	1.05
Skin (adult)	10.0	20.4	4.2	64.5	0.2 Na, 0.1 P, 0.2 S, 0.3 Cl, 0.1 K	1.09

Methods:

Calculations of stopping power

SP is a convenient variable that describes the effects of particle radiation in materials and predicts the ionization properties of the target matter. SP is defined by the ICRU (International Commission on Radiation Units and Measurements) as the ratio of the differential energy loss for a particle within the target matter to the corresponding differential path length of travel:

$$S = -\frac{dE}{dx} \quad \text{---------}\mathbf{1}$$

Where –dE/dx is known as the rate of energy loss or simply specific energy loss and the negative sign makes the result positive. Here, S is in negative sign because the energy of charged particles gradually decrease as long as they are interacting with the material. When the particles velocity decrease, S starts to increase (10). The total SP is defined as the sum of nuclear SP and electronic SP:

$$S_{tot}(E) = S_{el}(E) + S_{nuc}(E) \quad \text{--------}\ \mathbf{2}$$

At high velocity, slowing down of a projectile particle due to the inelastic collisions with the target's electrons is referred as the electronic SP (11). It is problematic to determine the electronic SP at energies below 100 keV. At low velocity, the nuclear SP arises from elastic Coulomb collisions with the target's nucleons and lose energy quickly. The nuclear SP is so small compared to electronic SP that it is only significant at very low energies (12). In this study, the nuclear SP is not counted because protons SP are calculated at high energies up to 350 MeV for clinically relevant work. So, here total SP means entire electronic SP and neglected nuclear SP.

Bethe is a common formula to determine SP of any charged particle. According to the Bethe formula, the stopping power of the charged particle will increase as the charged particle starts to collide with matter and decreases its energy (13). This formula agrees very well with the experiment at high energies because the charged particle does not carry any electrons with it (14). So, this formula requires no correction in this study. This formula can be described using relativistic quantum mechanics. For heavy charged particles like proton, the equation is:

$$-\frac{dE}{dx} = \frac{4\pi n z^2 k_0{}^2 e^4}{mv^2}[\ln\frac{2mv^2}{I} - \ln(1-\beta^2) - \beta^2] \quad \text{-------}\ \mathbf{3}$$

Where,

e= electronic charge, k= $1/4\pi\varepsilon_0$, v= velocity of the particle, m= electron rest mass, z= multiple of electron charge, I= mean excitation potential of the absorber, n= number of electrons per unit volume in the absorber, β= v/c (v is the speed of the particle and c is the speed of light in a vacuum)

The mean excitation potential of the absorber $I = \hbar\omega$ is one of the challenging parameters in the Bethe formula to evaluate. It is the only nontrivial material property in this formula. The SP of protons mostly depends on the accuracy of the mean excitation potential of the absorber, I. The mean excitation potential of the absorber should be determined by experiment to get accurate results.

But there are three major theories to determine the value of I. First is to use the dipole oscillator strength spectrum for the nth energy level over the logarithmic excitation energy range (15). But this method is difficult because of calculational complexity and more based on experimental research. In this study, here is some fixed materials like C, N, Na, K, etc. those have low atomic numbers (<40), so an empirical formula is employed. Dalton and Turner proposed that mean excitation potential is more close to the atomic number specially when the atom has a lower atomic number (<40). This formula gave reasonable agreement with the experimental values in previous author's work (16). The empirical equation is (17):

$I = 11.2 + 11.7Z, Z \leq 13$ ---------- **4**

$I = 9.76Z + \frac{58.5}{Z^{0.19}}, Z \geq 13$ ------------------ **5**

The speed of a charged particle is commensurable to the speed of light that requires relative correction and so Bethe-Bloch formula is also called relative correction formula. β is the proton's velocity and can be determined by experiment or employing,

$E = \frac{1}{2}mv^2$ **Or,** $v = \sqrt{\frac{2E}{m}}$ --------------- **6**

Here, the number of electrons per unit volume in the absorber can be calculated by,

$n = \frac{N_A.Z.\rho}{A.M_u}$ ------------ **7**

Where, Z= atomic number of the target material, ρ= density of the target material, N_A= Avogadro number, A= atomic mass of the target material, M_u= molar mass constant.

Comparisons with SRIM method:

SRIM (Stopping and Range of Ions in Matter) is an immensely popular program in the ion implementation research, computer program. SRIM has provided valid and approximately experimental results in previous radiation material research papers among other programs like ASTAR, MSTAR, PSTAR, etc. Though experimental measurement of SP is quite a challenging task so we choose the SRIM program to generate data. SRIM program's calculation method is based on this Bethe formula:

$$S = \frac{4\pi r_0^2 m_e c^2 Z_2}{\beta^2} Z_1^2 [f(\beta) - \ln < I > - \frac{C}{Z_2} - \frac{\delta}{2}]$$

-------------- **8**

Or, $S = \frac{kZ_2}{\beta^2} Z_1^2 [L_0(\beta) + Z_1 L_1(\beta) + Z_2^2 L_2(\beta)...]$,

where $k \equiv 4\pi r_0^2 m_e c^2$

And L_0, L_1, L_2 are called respectively correction factors of the Fano formula, Barkas correction, Bloch correction. After introducing stopping number L(β), this eq becomes,

$S = \frac{kZ_2}{\beta^2} Z_1^2 L(\beta)$ -------------- **9**

Bethe formula has some limitations specially when particles come with low velocity because at this velocity positively charged particle has a tendency to pick up electrons from the target materials (18). This process reduces its charge effectively and leads to a consequent linear energy loss of this charged particle. So, there is a good possibility that the charged particle accumulates with electrons and at the end becomes a neutral atom. SRIM program is based on this above corrected Bethe formula so that this program can calculate SP of any particle (low particle energy to high particle energy up to 2 GeV/amu) simultaneously (19). But in this study, the protons SP are calculated at energies ranging from 1 MeV to 350 MeV for clinically relevant work. As the study is entirely based on protons high energy, so the low-velocity limit of the Bethe formula is neglected.

The mean excitation potential is an important parameter which characterizes the stopping of target materials. From equation 8, mean excitation potential is defined as:

$\ln < I >= \sum f_n \ln E_n$ --------------- **10**

Where I and E_n has the same unit of eV. Bloch had shown that mean excitation potential is practically proportional to the atomic number (Z) of the target materials and close to Rydberg energy $I = 13.5Z.eV$. In this program, the Rydberg energy equation is used to calculate the mean excitation potential of all the materials. But, the mean excitation potential is calculated from equations 4 and 5 in this work. The atomic number of the material is taken into account whether it is greater than 13 or not. Because, body tissues are composed of different materials such as H, C, N, O, Na, P, etc. and they have different atomic numbers. These two equations are employed to get proper mean excitation potential values in this study for the theoretical calculations of the protons SP.

Calculations of range

Range, R of a charged particle is defined as the distance of that charged particle travel from its source to the target material. Light particles like electrons, positrons can be scattered in the path of the targets with large angles due to their low weight and it is difficult to calculate their path length. Monte Carlo methods that are based on a broad class of computational algorithms have been using in a successful manner specially for calculating the path length of light particles. On the other hand, the path length of heavy particles like protons is almost straight line. The range of protons can be calculated by some numerical integration methods. But the Continuous slowing down approximation (CSDA) is a simple and common method to calculate the range of the heavy particles like protons in the targets and this method is employed in this study. Incident particles continuously lose their energy in the path of the targets and the CSDA method neglects energy loss fluctuations. The range, R for an incident proton in the CSDA method is given as:

$$R = \rho \int_{E_f}^{E_0} \frac{dE}{S(E)} \quad \text{-----------------} \quad \textbf{11}$$

Where,
ρ= density of the target material,
E_o= initial energy of incident charged particle in material,
E_f= final energy of incident charged particle in material.

Results and Discussion:

Ageing is a continuous process of natural change that brings many changes in the fundamental compositions of most soft and hard body tissues. Genetics, state of health, sex, disease, physical activity, metabolism, nutrition are the main factors that are affecting the body compositions. The aim of this study is to show how ageing can be an affecting factor in order to determine the SP and range of protons energy.

From eq. 3, the SP of protons are calculated at the energies ranging from 1MeV to 350 MeV of blood, brain, skeleton-cortical-bone, and skin for both child and adult. Then these data are compared with the data obtained from the SRIM code. Previous papers on SP and range of proton efficiently showed that SRIM code was the best fit with their values compared to other programs (20). And, the percentage difference of this theoretical work has been compared with the values of SRIM code in Table 2 and 3 and also illustrated graphically in Fig.1**.**

Table 2. Showing the proton energy in MeV and the stopping power for values for Blood and Brain in MeV/g/cm^2.

Energy (MeV)	Stopping power in MeV/g/cm^2 for Blood (child)			Stopping power in MeV/g/cm^2 for Blood (adult)			Stopping power in MeV/g/cm^2 for Brain (child)			Stopping power in MeV/g/cm^2 for Brain (adult)		
	SRIM	This work	%T	SRIM	This work	%T	SRIM	This work	%T	SRIM	This work	%T
1	250.50	283.15	13.03	250.20	282.18	12.78	250.31	282.71	12.94	250.81	284.55	13.45
2	163.21	189.67	16.21	162.81	188.43	15.74	163.91	190.14	16.00	163.62	190.03	16.14
3	119.97	138.23	15.22	119.68	137.66	15.02	120.48	139.41	15.71	120.28	139.17	15.71
4	95.92	107.75	12.33	95.68	106.68	11.50	96.27	108.38	12.58	96.12	108.21	12.58
5	80.45	86.29	7.26	80.27	85.51	6.53	80.76	86.45	7.05	80.63	86.35	7.09
6	69.62	74.81	7.45	69.46	74.02	6.56	69.87	75.06	7.43	69.76	74.94	7.43
7	61.56	66.39	7.85	61.42	66.14	7.68	61.78	66.79	8.11	61.69	66.53	7.85
8	55.30	59.61	7.79	55.17	59.44	7.74	55.50	60.07	8.23	55.41	59.88	8.07
9	50.29	53.22	5.83	50.18	52.91	5.44	50.48	53.32	5.63	50.39	53.19	5.56
10	46.19	48.42	4.83	46.09	48.12	4.40	46.36	48.53	4.68	46.29	48.47	4.71
20	26.26	28.38	8.07	26.21	28.28	7.90	26.36	28.51	8.16	26.32	28.45	8.09
30	18.87	20.91	10.81	18.84	20.83	10.56	18.95	20.99	10.77	18.92	20.95	10.73
40	14.96	16.25	8.62	14.93	16.13	8.04	15.02	16.28	8.39	14.99	16.27	8.54
50	12.51	13.61	8.79	12.48	13.56	8.65	12.56	13.71	9.16	12.53	13.65	8.94
60	10.83	11.59	7.02	10.81	11.52	6.57	10.87	11.65	7.18	10.85	11.62	7.10
70	9.59	10.35	7.92	9.58	10.33	7.83	9.63	10.44	8.41	9.61	10.39	8.12
80	8.65	9.36	8.21	8.64	9.32	7.87	8.69	9.42	8.40	8.67	9.40	8.42
90	7.91	7.55	4.55	7.90	7.53	4.68	7.94	7.62	4.03	7.92	7.58	4.29
100	7.31	7.09	3.01	7.30	7.05	3.42	7.34	7.11	3.13	7.33	7.10	3.14
125	6.21	5.76	7.24	6.20	5.75	7.26	6.24	5.79	7.21	6.23	5.77	7.38
150	5.46	5.03	7.88	5.45	5.01	8.07	5.48	5.07	7.48	5.47	5.05	7.68
175	4.91	4.66	5.09	4.90	4.64	5.31	4.93	4.68	5.07	4.92	4.67	5.08
200	4.50	4.37	2.89	4.49	4.35	3.12	4.52	4.39	2.88	4.51	4.38	2.89
225	4.18	3.98	4.78	4.17	3.96	5.04	4.19	3.98	5.01	4.18	3.98	4.78
250	3.92	3.68	6.12	3.91	3.66	6.39	3.93	3.70	5.85	3.92	3.68	6.12
275	3.70	3.31	10.54	3.69	3.29	10.84	3.72	3.35	9.95	3.71	3.33	10.24
300	3.52	3.07	12.78	3.51	3.06	12.82	3.54	3.09	12.71	3.53	3.08	12.75
350	3.24	2.82	12.96	3.24	2.82	12.96	3.26	2.85	12.58	3.25	2.84	12.62

Table 3. Showing the proton energy in MeV and the stopping power for values for Skeleton-cortical-bone and Skin in MeV/g/cm^2.

Energy (MeV)	Stopping power in MeV/g/cm^2 for Skeleton-cortical-bone (child)			Stopping power in MeV/g/cm^2 for Skeleton-cortical-bone (adult)			Stopping power in MeV/g/cm^2 for Skin (child)			Stopping power in MeV/g/cm^2 for Skin (adult)		
	SRIM	This work	%T	SRIM	This work	%T	SRIM	This work	%T	SRIM	This work	%T
1	214.26	242.67	13.26	211.26	236.37	11.89	250.00	281.88	12.75	251.80	284.31	12.91
2	138.49	160.13	15.63	136.49	155.51	13.94	162.91	188.69	15.82	163.21	190.20	16.54
3	102.76	117.38	14.23	101.46	115.44	13.78	119.78	137.81	15.05	119.98	139.42	16.20
4	82.73	90.45	9.33	81.66	88.96	8.94	95.75	106.79	11.53	95.87	108.10	12.76
5	69.72	75.76	8.66	68.85	74.79	8.63	80.33	85.57	6.52	80.42	87.25	8.49
6	60.52	65.13	7.62	59.79	64.36	7.64	69.51	74.17	6.70	69.58	75.69	8.78
7	53.66	58.21	8.48	53.02	57.63	8.69	61.46	66.23	7.76	61.53	67.19	9.20
8	48.32	52.32	8.28	47.75	51.48	7.81	55.21	59.51	7.79	55.28	60.28	9.04
9	44.01	48.19	9.50	43.51	46.86	7.70	50.22	52.99	5.52	50.28	53.36	6.13
10	40.49	43.11	6.47	40.02	42.72	6.75	46.12	48.19	4.49	46.18	48.43	4.87
20	23.23	25.68	10.55	22.99	25.04	8.92	26.23	28.35	8.08	26.29	28.56	8.63
30	16.77	18.09	7.87	16.60	17.85	7.53	18.85	20.86	10.66	18.91	21.07	11.42
40	13.32	14.76	10.81	13.19	14.48	9.78	14.94	16.16	8.17	14.99	16.38	9.27
50	10.35	11.41	10.24	11.04	11.79	6.79	12.49	13.59	8.81	12.54	13.75	9.65
60	9.67	10.49	8.48	9.58	10.24	6.89	10.82	11.55	6.75	10.87	11.69	7.54
70	8.58	9.13	6.41	8.50	8.93	5.06	9.58	10.34	7.93	9.58	10.34	7.93
80	7.75	8.17	5.42	7.68	8.02	4.43	8.64	9.32	7.87	8.65	9.35	8.09
90	7.09	7.34	3.53	7.02	7.06	0.57	7.90	7.53	4.68	7.90	7.53	4.68
100	6.55	6.67	1.83	6.49	6.59	1.54	7.30	7.05	3.42	7.30	7.06	3.29
125	5.58	5.63	0.90	5.52	5.49	0.54	6.20	5.75	7.26	6.20	5.75	7.26
150	4.90	4.84	1.22	4.86	4.70	3.29	5.45	5.01	8.07	5.45	5.01	8.07
175	4.42	4.27	3.39	4.38	4.21	3.88	4.91	4.64	5.50	4.91	4.64	5.50
200	4.05	3.91	3.46	4.01	3.82	4.74	4.49	4.35	3.12	4.49	4.35	3.12
225	3.76	3.57	5.05	3.72	3.51	5.65	4.17	3.96	5.04	4.17	3.96	5.04
250	3.53	3.31	6.23	3.49	3.25	0.86	3.91	3.66	6.40	3.91	3.66	6.39
275	3.33	3.11	6.61	3.30	3.06	7.27	3.70	3.29	11.08	3.70	3.29	11.08
300	3.17	2.92	7.89	3.15	2.87	8.89	3.52	3.06	13.07	3.52	3.06	13.07
350	2.92	2.61	10.62	2.90	2.58	11.03	3.24	2.82	13.96	3.24	2.82	13.96

From Tables of 2 and 3, the total percentage difference between SRIM and this work is 8.40%, 8.24%, 8.38%, 8.41%, 7.57%, 6.91%, 8.31%, 8.85% respectively for blood (child), blood (adult), brain (child), brain (adult), skeleton-cortical-bone (child), skeleton-cortical-bone (adult), skin (child), skin (adult). The percentage difference rate for all tissues is less than 10% which shows that this result is in good agreement with SRIM. Figure-1 shows the SP gradually decreases with the increase of protons energy.

Moreover, the difference between these work values and SRIM values at energies ranging from (1-10) MeV is quite high but there is almost no difference at energies ranging from (80-350) MeV. Because when proton enters in the target tissue, they start to interact with many electrons where the proton transfer energy in this encounter mostly by excitation and ionization (21). So, the SP of proton starts to decrease with the increase of proton velocity that is shown in Fig. 1.

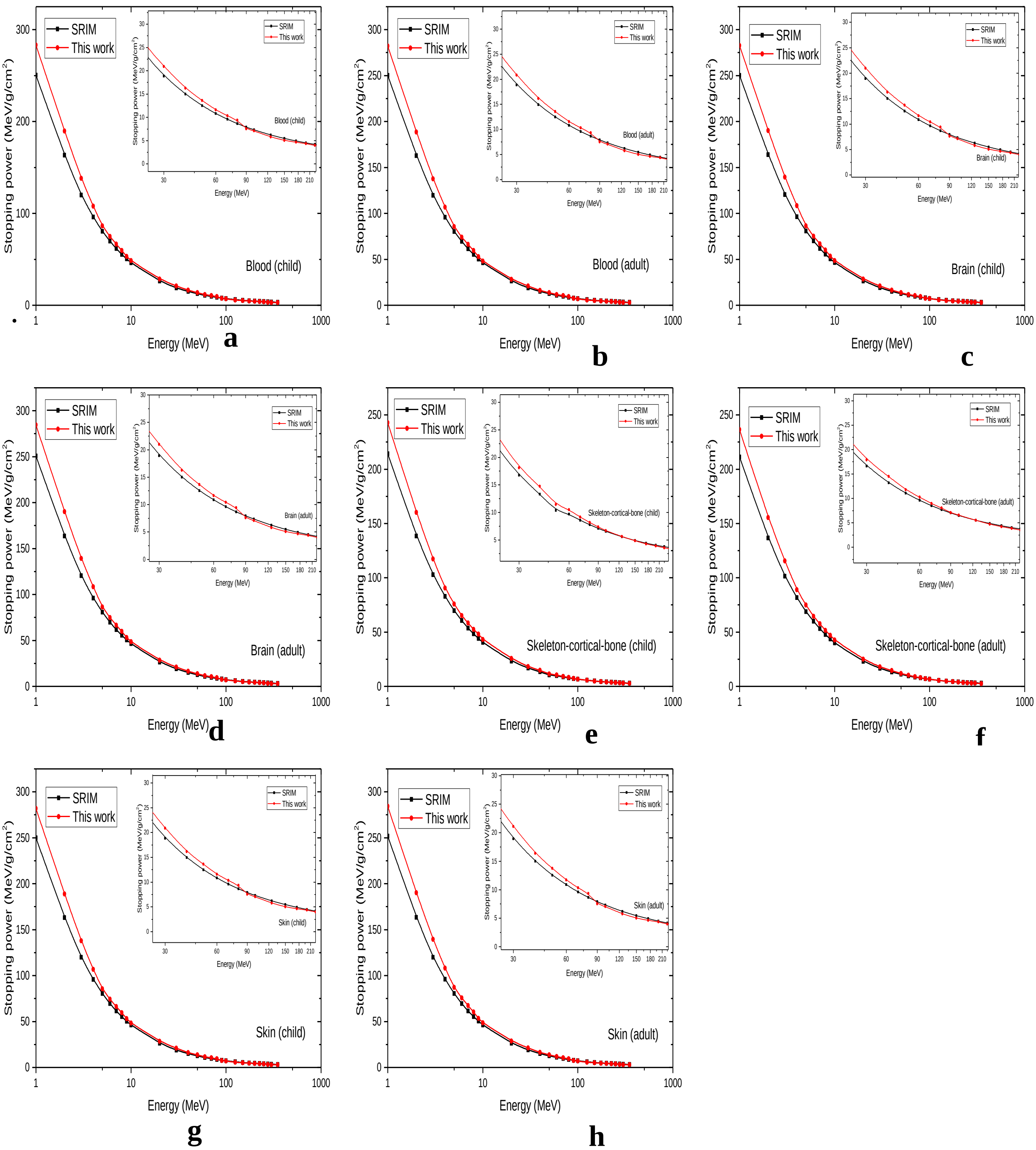

Figure 1.a) The stopping power of blood (child) as a function of proton's energy. b) The stopping power of blood (adult) as a function of proton's energy. c) The stopping power of brain (child) as a function of proton's energy. d) The stopping power of blood (adult) as a function of proton's energy. e) The stopping power of skeleton-cortical-bone (child) as a function of proton's energy. f) The stopping power of skeleton-cortical-bone (adult) as a function of proton's energy. g) The stopping power of skin (child) as a function of proton's energy. h) The stopping power of skin (adult) as a function of proton's energy

From eq.11, the CSDA range of protons are calculated at energies ranging from (1-350MeV) and compared with the SRIM code. Results are tabulated in Table 4 and 5 and also illustrated graphically proton range in cm vs. proton energy in MeV in Fig.2. From Table 4 and 5, the total percentage difference between SRIM and this work are 8.15%, 7.94%, 8.04%, 8.14%, 7.15%, 6.82%, 8.32%, 8.73% respectively for blood (child), blood (adult), brain (child), brain (adult), skeleton-cortical-bone (child), skeleton-cortical-bone (adult), skin (child), skin (adult). The percentage difference rate for all tissues is less than 10% which shows that this result is in a good agreement with SRIM.

Table 4. Proton range for Blood (child and adult) and Brain (child and adult) for proton energy 1MeV to 350MeV.

Energy (MeV)	Blood (child) cm			Blood (adult) cm			Brain (child) cm			Brain (adult) cm		
	SRIM	This work	%T	SRIM	This work	%T	SRIM	This work	%T	SRIM	This work	%T
1	0.00427	0.00377	11.71	0.00423	0.00379	10.40	0.00399	0.00364	8.77	0.00414	0.00365	11.84
2	0.00655	0.00564	13.89	0.00649	0.00567	12.63	0.00628	0.00541	13.85	0.00635	0.00547	13.86
3	0.01783	0.01548	13.18	0.01767	0.01554	12.05	0.01709	0.01477	13.58	0.01729	0.01494	13.59
4	0.03346	0.02979	10.97	0.03315	0.03008	9.26	0.03209	0.02851	11.16	0.03245	0.02883	11.16
5	0.05320	0.04960	6.77	0.03952	0.05005	6.64	0.05101	0.04765	6.59	0.05159	0.04817	6.63
6	0.07684	0.07151	6.94	0.07613	0.07227	5.07	0.07370	0.06861	6.91	0.07454	0.06938	6.92
7	0.10428	0.09670	7.27	0.10331	0.09706	6.05	0.10003	0.09252	7.51	0.10115	0.09379	7.28
8	0.13543	0.12565	7.22	0.13417	0.12600	6.09	0.12990	0.12002	7.61	0.13138	0.12157	7.47
9	0.17021	0.16084	5.50	0.16862	0.16178	4.06	0.16323	0.15453	5.33	0.16511	0.15642	5.26
10	0.20847	0.19889	4.60	0.20653	0.20012	3.10	0.19995	0.19101	4.47	0.20219	0.19310	4.50
20	0.77417	0.71635	7.47	0.76694	0.71888	6.27	0.74241	0.68125	8.24	0.75076	0.69456	7.49
30	1.64440	1.48398	9.76	1.62904	1.48967	8.56	1.57625	1.42305	9.72	1.59408	1.43961	9.69
40	2.78943	2.56800	7.94	2.76336	2.58710	6.38	2.67443	2.46744	7.74	2.70580	2.49293	7.87
50	4.19104	3.85231	8.08	4.15187	3.86651	6.87	4.01831	3.68125	8.39	4.06703	3.73333	8.21
60	5.82917	5.44693	6.56	5.77469	5.48003	5.10	5.59061	5.21630	6.70	5.65529	5.28055	6.63
70	7.69864	7.13334	7.34	7.62669	7.14714	6.29	7.38006	6.80747	7.76	7.46722	6.90664	7.51
80	9.77224	9.03098	7.59	9.68092	9.06974	6.31	9.36363	8.63800	7.75	9.47635	8.74042	7.77
90	12.0392	12.6132	4.77	11.9267	12.6467	6.04	11.5453	12.0301	4.20	11.6808	12.2111	4.54
100	14.4911	14.9407	3.10	14.3557	15.0255	4.67	13.8928	14.3417	3.23	14.0464	14.5014	3.24
125	21.3655	23.0347	7.81	21.1659	23.0748	9.02	20.4679	22.0578	7.77	20.6998	22.3501	7.97
150	29.1996	31.6958	8.55	28.9267	31.8224	10.01	28.0055	30.2702	8.09	28.3291	30.6851	8.32
175	37.9185	39.9527	5.36	37.5615	40.1250	6.82	36.3529	38.2949	5.34	36.7805	38.7495	5.35
200	47.3178	48.7254	2.97	46.8756	48.9494	4.42	45.3473	46.6902	2.96	45.8891	47.2511	2.97
225	57.3397	60.2211	5.03	56.8038	60.5252	6.55	55.0644	57.9698	5.28	55.7321	58.5327	5.03
250	67.9668	72.3994	6.52	67.3316	72.7951	8.11	65.2595	69.3162	6.22	66.0612	70.3696	6.52
275	79.2378	88.5740	11.78	78.4973	89.1124	13.52	75.8656	84.2448	11.04	76.8086	85.5736	11.41
300	90.8890	104.211	14.66	90.0398	104.552	16.12	86.9972	99.6667	14.56	88.0907	100.961	14.61
350	115.256	132.422	14.89	114.179	132.421	16.98	110.267	126.129	14.69	111.680	127.803	14.84

Table 5. Proton range for Skeleton-cortical-bone (child and adult) and Skin (child and adult) for proton energy 1MeV to 350MeV.

Energy (MeV)	Skeleton-cortical-bone (child)cm			Skeleton-cortical-bone (adult)cm			Skin (child) Cm			Skin (adult) cm		
	SRIM	This work	%T	SRIM	This work	%T	SRIM	This work	%T	SRIM	This work	%T
1	0.00854	0.00754	11.71	0.00908	0.00812	10.57	0.00420	0.00355	15.48	0.00432	0.00357	17.36
2	0.01321	0.01142	13.55	0.01406	0.01234	12.23	0.00644	0.00556	13.66	0.00667	0.00573	14.09
3	0.03561	0.03118	12.44	0.03784	0.03326	12.10	0.01753	0.01524	13.06	0.01817	0.01563	13.98
4	0.06636	0.06069	8.54	0.07053	0.06474	8.21	0.03289	0.02950	10.31	0.03410	0.03024	11.32
5	0.10499	0.09662	7.97	0.11154	0.10268	7.94	0.05228	0.04908	6.12	0.05422	0.04997	7.84
6	0.15118	0.14048	7.08	0.16056	0.14916	7.10	0.07552	0.07078	6.28	0.07832	0.07200	8.07
7	0.20462	0.18862	7.82	0.21727	0.19989	8.00	0.10250	0.09513	7.19	0.10629	0.09733	8.43
8	0.26510	0.24483	7.65	0.28146	0.26107	7.24	0.13312	0.15852	9.08	0.15775	0.12657	9.77
9	0.33265	0.30379	8.68	0.35302	0.32778	7.15	0.16726	0.17430	4.21	0.19511	0.16341	6.25
10	0.40676	0.38204	6.08	0.43178	0.40449	6.32	0.20490	0.19610	4.29	0.21242	0.20256	4.64
20	1.49678	1.35397	9.54	1.58677	1.45686	8.19	0.76057	0.70370	7.48	0.78775	0.72514	7.95
30	3.16457	2.93366	7.30	3.35421	3.11932	7.00	1.61538	1.45974	9.63	1.67160	1.50023	9.25
40	5.35810	4.83536	9.76	5.67702	5.17127	8.91	2.74096	2.53403	7.55	2.83588	2.59523	8.49
50	8.66378	7.85889	9.29	8.48331	7.97964	5.94	4.11929	3.78587	8.09	4.25917	3.88436	8.80
60	11.1655	10.2926	7.82	11.8246	11.0625	6.45	5.72550	5.36363	6.32	5.91628	5.50128	7.01
70	14.7168	13.8302	6.02	15.5859	14.8353	4.82	7.56263	7.00677	7.35	7.85072	7.27369	7.35
80	18.6542	17.6952	5.14	19.7500	18.9127	4.24	9.60068	8.90021	7.30	9.95490	9.20962	7.49
90	22.9718	22.1894	3.41	24.3419	24.2039	0.57	11.8291	12.4103	4.91	12.2797	12.8831	4.91
100	27.6595	27.1619	1.80	29.2881	28.8437	1.52	14.2397	14.7447	3.55	14.7822	15.2847	3.40
125	40.6667	40.3055	0.89	43.1304	43.3661	0.55	21.0000	22.6435	7.83	21.8000	23.5060	7.83
150	55.6469	56.3367	1.24	58.8642	60.8681	3.40	28.7064	31.2275	8.78	29.8000	32.4172	8.78
175	72.0407	74.5714	3.51	76.2740	79.3539	4.04	37.2098	39.3750	5.82	38.6273	40.8750	5.81
200	89.9185	93.1381	3.58	95.2818	100.021	4.97	46.5367	48.0345	3.22	48.3098	49.8643	3.22
225	109.021	114.823	5.32	115.613	122.529	5.98	56.4029	59.3939	5.30	58.5516	61.6566	5.31
250	129.085	137.665	6.65	136.986	147.102	7.38	66.8670	71.4344	6.83	69.4143	74.1557	6.84
275	150.577	161.228	7.07	159.418	171.922	7.84	77.7568	87.4468	12.46	80.7189	90.7781	11.86
300	172.609	187.387	8.56	182.248	200.028	9.76	89.1903	102.598	15.03	95.5881	106.506	13.42
350	218.723	244.701	11.88	231.062	259.721	12.4	113.102	129.947	15.89	117.411	134.897	14.90

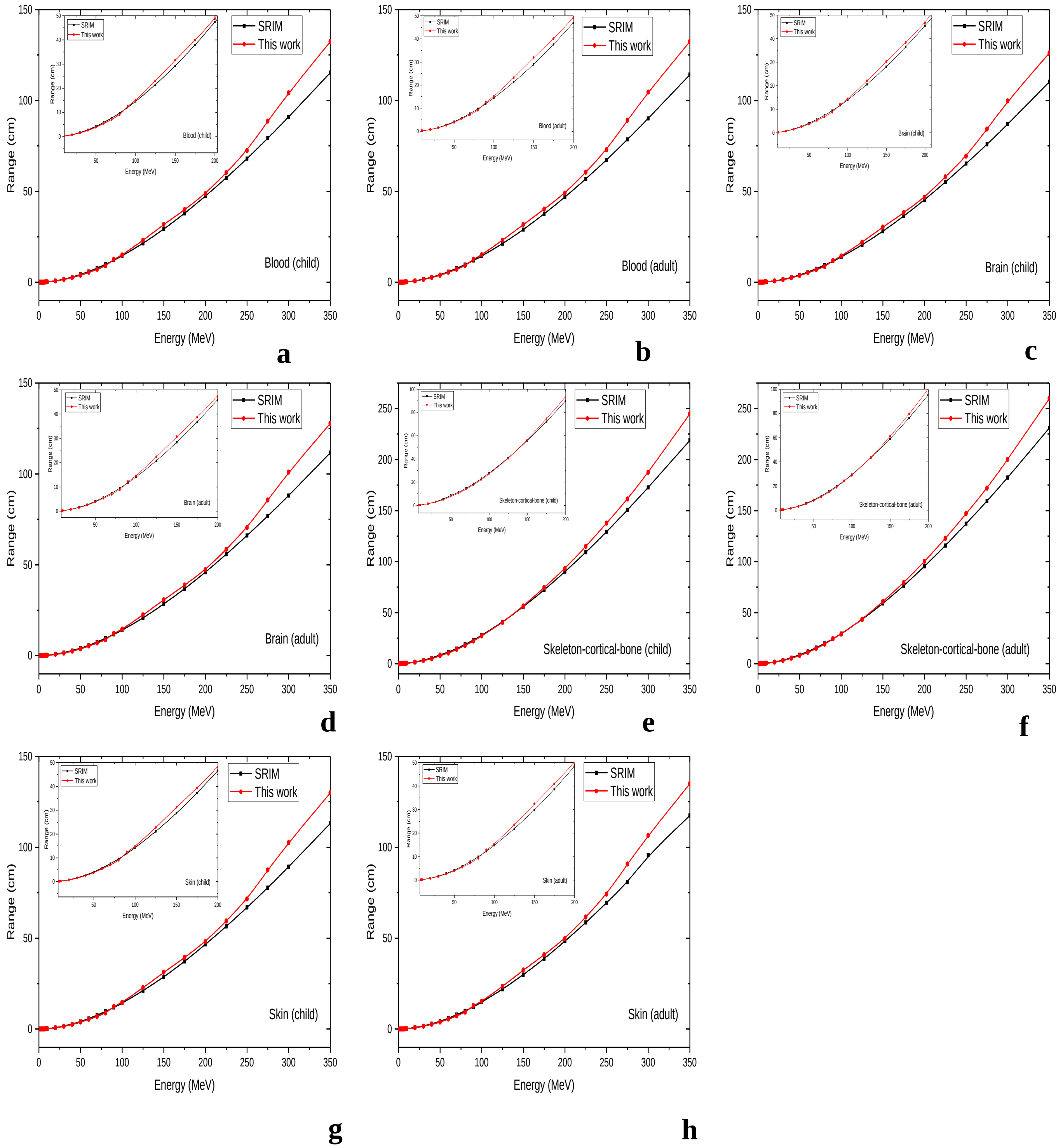

Figure 2. a) The CSDA ranges of proton in blood (child) tissue. b) The CSDA ranges of proton in blood (adult) tissue. c) The CSDA ranges of proton in brain (child) tissue. d) The CSDA ranges of proton in brain (adult) tissue. e) The CSDA ranges of proton in skeleton-cortical-bone (child) tissue. f) The CSDA ranges of proton in skeleton-cortical-bone (adult) tissue. g) The CSDA ranges of proton in skin (child) tissue. h) The CSDA ranges of proton in skin (adult) tissue.

In Fig. 2, the percentage difference starts to increase rapidly at 250 MeV or above. Protons tend to pick up electrons from the target tissues when the CSDA method is applied at high energies. And as a result, this will give rise to linear energy loss and deviations. This is the severe limitation of the CSDA method and so, we calculated the range of proton up to 350 MeV. In Fig. 2, this work shows the best fit with SRIM at the energy range (5-250MeV) and varies almost linearly with these energies. And then, the rise of the curve has started so rapidly beyond 250 MeV and demolish this linearity. The first reason behind this rapid rise is due to increasing bremsstrahlung probability and the other reason is the CSDA method which is discussed above(22).

Conclusion:

In this work, we have done the SP and range calculations for protons incident on the 4 different human tissues (blood, brain, skeleton-cortical-bone, skin) of both child and adult. Though ageing brings many changes in the fundamental compositions of most tissues, we got slight difference between child and adult values of SP and range. Furthermore, it is observed from these tables that our results are in good agreement with SRIM specially at the energy range 50-250 MeV and this energy interval is essential in the clinically relevant work like proton therapy. In addition, the result shows the effectiveness and reliability of this study. Although, the stability of this work starts to break beyond 250MeV. So, more research should be conducted to improve the accuracy of the SP and range computation.

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Authors' declaration:

- Conflicts of Interest: None.
- We hereby confirm that all the Figures and Tables in the manuscript are mine ours. Besides, the Figures and images, which are not mine ours, have been given the permission for re-publication attached with the manuscript.
- Ethical Clearance: The project was approved by the local ethical committee in University of Chittagong.

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قدرة التوقف وحسابات نطاق CSDA للبروتونات في أنسجة السرطان الشائعة لدى الإنسان

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الخلاصة:
في هذا البحث، حسبنا قدرة التوقف ومدى البروتونات في الأنسجة البشرية البيولوجية الصلبة واللينة (الدم والدماغ والعظام القشرية الهيكلية والجلد) لكل من الأطفال والبالغين في طاقات تتراوح من 1 Me إلى 350 MeV. قمنا بجمع البيانات من تقرير ICRU 46 وحساب قدرة التوقف باستخدام صيغة Bethe. وقد استخدمنا طريقة التكامل البسيط (تقريب التباطؤ المستمر) لحساب المدى للبروتونات عند الهدف. بعد ذلك، تمت مقارنة قدرة التوقف وقيمة المدى للبروتونات في أنسجة الإنسان بالبرنامج المسمى SRIM. علاوة على ذلك تم عرض نتائج قدرة التوقف مقابل الطاقة والمدى مقابل الطاقة بشكل بياني. تم ايجاد علاقة بين النتائج المكتسبة و SRIM وتتغير بشكل خطي تقريبًا مع طاقة تصل إلى 250 MeV

الكلمات المفتاحية: الأنسجة البشرية، البروتون، المدى، **SRIM**، قدرة التوقف.