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Mass Stopping Power and Range of Alpha Particles in Biological Human Body Tissues (Blood, Brain, Adipose and Bone)

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Abstract

The mass stopping power and range of alpha particles in biological human body tissues (blood, brain, adipose, and bone) were computed using the MATLAB Program at energies ranging from 0.2 MeV to 200 MeV. The Bethe Block formula was used to compute the mass stopping power. Furthermore, the alpha particle ranges at the tissues were calculated using the simple integration (continuous slowing down approximation) method. The results of mass-stopping power versus energy and range versus energy were graphed, and empirical equations for determining mass-stopping power and ranges were derived. The current results for mass-stopping powers and ranges of bone cortical and adipose tissues were compared to those produced by ASTAR results (Alpha Stopping Power and Range). They showed good agreement, especially for energies that extend from 1 to 200 MeV.

Subject Areas

Nuclear Technology, Radiology

Keywords

Human Body Tissues, Alpha Particles, MATLAB, Mass Stopping Power, Range

1. Introduction

In the majority of studies and applications involving radiation science, including those involving blood cancer, cell modification, radiation mutations, nuclear physics, and so forth, the energy loss and range of particles or ions in the air, tissues, and polymers are of great importance. One of the most important calculations in reducing the risk of radiation damage to tissue near the sick tissue during radiotherapy is the stopping power calculation [1].

In recent years, theoretical and experimental studies of the Stopping Power (SP) and range of charged particles have increased, especially in the field of radiation physics. This area has been the subject of numerous successful theoretical and experimental studies [2].

Because the Bragg curve can transfer energy in the form of point shots through diseased tissue while maintaining the target dose and delivering a higher dose to the tumor (3), the use of heavier ions or alpha particles as an alternative to external photon beams in radiotherapy is increasing [3].

Charged particles are commonly utilized in radiotherapy due to their precise tissue penetration and the fact that their depth relies on both the type of material being treated and incident particle energy. Charged particles, including as alpha particles, deuterons, and protons, are important in radiotherapy because of their ability to transmit energy to the target [4]. Therefore, exact knowledge of the stopping power and range of alpha particles is necessary for the precise dosimetry of alpha radiation. Researching the stopping power and range of alpha in biological tissues requires identifying or gathering information from research studies or ICRU reports.

Alpha particles, on the other hand, are the least invasive and hence lose more energy by ionizing the target's atoms. This is why alpha particles are the most harmful to health [5].

The stopping power is the rate of loss of energy per unit length ($\mathrm{d}E/\mathrm{d}x$). It depends on the speed and charge of both the fallen particles and the target material [1].

An early study of the energy loss of charged particles traveling through materials yields the following general formula for stopping power:

$$-\frac{\mathrm{d}E}{\mathrm{d}X}=\frac{4\mu e^4 N Z_2}{mv^2}Z_1^2 B \tag{1}$$

where: N is the target density, Z_2 is the target atomic number, m is the electron mass, v and Z_1 are the projectile velocity and charge respectively and B is called the "stopping number" [6].

The negative sign in Equation (1) signifies the fact that the particles lose energy as they pass through the material. For most practical purposes, the physics of the energy loss phenomena is complex and will be not covered in detail [7].

When an ion beam enters a solid, it loses energy via collisions with target nuclei and electrons (electronic stopping and nuclear stopping, respectively) [8]. The stopping power owing to nuclear and electrical interactions is then simply added together to determine the total stopping power. It is also possible to ignore the nuclear component of the stopping power [9].

Stopping power is the energy loss of charged particles in matter.

The charged particle suffers from loss of energy per unit of distance, which is referred as $-\frac{\mathrm{d}E}{\mathrm{d}X}$ is conventionally known as the stopping power. This basic quantity is calculated using quantum and mechanical quantum theories. It is important to express $-\frac{\mathrm{d}E}{\mathrm{d}X}$ in terms of the properties specifying the incident charged particle, such as its velocity v and charge and the properties pertaining to the atomic medium, the charge of the atomic nucleus, the density of atoms, and the average ionization potential. R.D. Evan and W.E. Meyerhof consider only a crude, approximate derivation of the formula for $-\frac{\mathrm{d}E}{\mathrm{d}X}$. They begin with an estimate of the energy loss suffered by an incident charged particle when it interacts with a free and initially stationary electron. Referring to a collision cylinder whose radius is the impact parameter b and whose length is the small distance traveled $\mathrm{d}x$ [10].

Because the stopping power depends on the energy of particle, then it is possible to calculate the path of the particle which corresponds to the lower particle energy from the initial value E_0 to some smaller value E_1. Based on the definition of the stopping power, that path is equal to the integral:

$$R = \int_{E_1}^{E_0} \frac{\mathrm{d}E}{-\frac{\mathrm{d}E}{\mathrm{d}X}} \tag{2}$$

In general, the particle's range does not correspond to the particle's penetration depth. The penetration depth is defined as the greatest gap between the material's surface and the particle as it goes into the substance. The penetration depth is determined by the geometry of the particle's trajectory and is always less than the range. Because the interaction with the material's atoms is random, various particles will be deflected differently, resulting in varied penetration depths (even if those particles are identical and have similar beginning energies). However, their material ranges will be quite comparable (practically equal). Because of the irregular trajectories of electrons, the discrepancy between range and penetration depth is extremely pronounced. Heavy charged particles, on the other hand, have a range that is nearly equal to their penetration depth (assuming the particle beam is normal to the material's surface), since they move in straight lines [10].

The objective of the present work is to calculate the mass stopping power and the range of alpha particles for the tissues under consideration at energies ranging from 0.2 MeV to 200 MeV. Also, we try to compare the obtained results of mass stopping power and range with available ASTAR data.

2. Method for Calculating Mass Stopping Power and Ranges

Bethe Block conducted the first quantum mechanical research of stopping power. When the projectile's velocity exceeds the Bohr velocity, the Bethe Block theory of stopping is valid. The target is supposed to be an elemental material in Bethe theory. Bethe's approach to energy loss is based on the born approximation, which is applied to inelastic collisions between heavy particles and atomic electrons. The projectile heavy particle is supposed to be structure less in this theory, while the target nucleus is assumed to be indefinitely massive [11].

2.1. Calculations of Electronic Stopping Power

The following Bethe Block stopping power equation has been used for energy range 0.2 - 200 MeV [3] [12] [13]:

$$-\frac{\mathrm{d}E}{\mathrm{d}X}=\frac{5.08\times10^{-31}z^2n}{\beta^2}\left[F(\beta)-\ln I\right] \quad (3)$$

where: β is v/c where v is the velocity of alpha particles and c is light speed, I is the mean excitation energy and $F(\beta)$ is given by:

$$F(\beta)=\ln\ln\frac{1.02\times10^6\beta^2}{1-\beta^2}-\beta^2$$

n is calculated using the following relation:

$$n=\frac{\rho z N_a}{A}$$

where: N_a is Avogadro number, ρ is the density of substances and Z/A is the ratio of atomic number to the mass number of substances. The basic data for calculating mass stopping powers which is equal to the electronic stopping power divided by the density of the tissues and are tabulated in **Table 1**. The elemental composition of blood, Braine, Bone and Adipose tissues are given in **Table 2**. It is well known that human tissue chemical compositions play a significant role in the investigation of micro diametric distributions in irradiated human beings [1]. Then Equation (3) is used to find the values of stopping power and then we divided it by the density of the tissues to find mass stopping power for all the energy values for all tissues. All calculations were done using MATLAB program.

The percentage deviation error for the present results of mass stopping power and that of ASTAR results of bone cortical and adipose tissues results are calculating by the following relation

$$\text{Deviation Error}=\left(\frac{\text{Present Result}-\text{ASTAR Result}}{\text{ASTAR Result}}\right)\times100\% \quad (4)$$

Table 1. Basic Data for calculating mass stopping powers.

Material	<Z\A>	I (eV)	Density(ρ) (g/cm^3)	$n=\frac{\rho z N_a}{A}$ (electrons/m^3)
Blood, Whole (ICUR-44)	0.54999	75.2	1.060E+00	3.51542×10^{29}
Bone, Cortical (ICRU-44)	0.51478	112.0	1.920E+00	5.95991×10^{29}
Brain, Grey\White Matter (ICUR-44)	0.55239	73.9	1.040E+00	3.46414×10^{29}
An adipose tissue (ICRU-44)	0.55579	64.8	9.500E−01	3.1838×10^{29}

Table 2. Elemental composition of blood, bone, Braine and Adipose tissues.

Material	Composition
Blood, Whole (ICUR-44)	1:0.102000 H 6:0.110000 Ca 7:0.033000 N 8:0.745000 O 11:0.001000 Na 15:0.001000 P 16:0.002000 S 17:0.003000 Cl 19:0.002000 K 26:0.001000 Fe
Bone, Cortical (ICRU-44)	1:0.034000 H 6:0.155000 C 7:0.042000 N 8:0.435000 O 11:0.001000 Na 12:0.002000 Mg 15:0.103000 P 16:0.003000 S 20:0.225000 Ca
Brain, Grey\White Matter (ICUR-44)	1:0.107000 H 6:0.145000 C 7:0.022000 N 8:0.712000 O 11:0.002000 Na 15:0.004000 P 16:0.002000 S 17:0.003000 Cl 19:0.003000 K
An adipose tissue (ICRU-44)	1:0.114000 H 6:0.598000 C 7:0.007000 N 8:0.278000 O 11:0.001000 Na 16:0.001000 S 17:0.001000 Cl

2.2. Calculations of Alpha Particles Range

A heavy particle's range is defined as the straight path it takes inside the target. Due to their low weight and difficulty in calculating their journey length, light particles like electrons and positrons can scatter in the path of targets at enormous angles. For determining the path length of light particles in particular, Monte Carlo techniques built on a wide range of computing algorithms have been utilized successfully. In contrast, the travel length of heavier particles, such as alpha particles, is nearly linear. Some numerical integration techniques can be used to calculate the alpha particle range. But the Continuous Slowing Down Approximation (CSDA) is a simple and common method to calculate the range of the heavy particles like alpha particles 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. to find range of a given tissues Equation (2) is used. All calculations were done using MATLAB program.

3. Results and Discussion

The Bethe Block theory and the MATLAB application were used in the current work to determine the mass stopping power and range of alpha particles in four tissues of the human body (brain, bone, adipose and blood tissues). The results of mass stopping powers of brain, bone, adipose and blood tissues respectively are given in Table 3. In Table 4 the range of alpha particles for bone, brain, adipose and blood tissues respectively are given. In Table 5 a comparison between the present results and that of ASTAR results of mass stopping powers of adipose and bone cortical tissues are given while a comparison between the present results and that of ASTAR result of alpha particles range for bone cortical and adipose tissue are given in Table 6. To study the relation between the mass stopping power and the alpha particles energy the graphical method is used as shown in Figures 1-4 for the tissues under consideration and the empirical formula for calculating mass stopping powers knowing alpha particles energy are obtained for all tissues under study as given in Table 7. In Figures 5-7 the relation between the range and alpha particles for the tissues under study are shown while the empirical formula for calculating alpha particles range of all

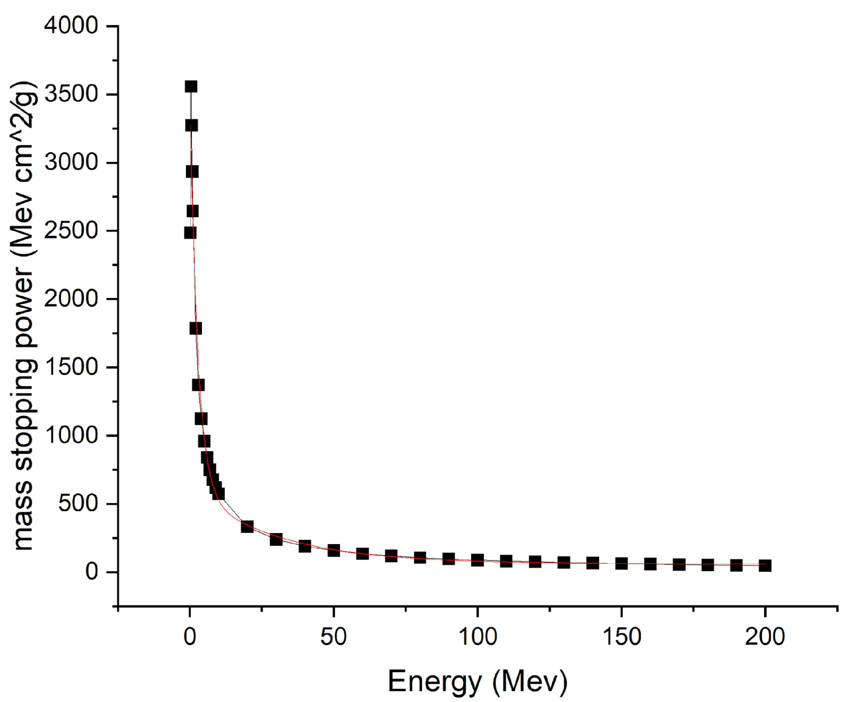

Figure 1. Mass stopping power of blood versus energy of Alpha particles.

Table 3. Values of mass stopping power (MeV cm²/g) of brain, bone cortical, Adipose and blood tissues.

Energy (MeV)	$\frac{dE}{dx\rho}\left(\frac{MeV\cdot cm^2}{g}\right)$ Brain	$\frac{dE}{dx\rho}\left(\frac{MeV\cdot cm^2}{g}\right)$ Bone	$\frac{dE}{dx\rho}\left(\frac{MeV\cdot cm^2}{g}\right)$ Adipose tissue	$\frac{dE}{dx\rho}\left(\frac{MeV}{g}\right)$ Blood
0.2	2466.13725001659	153.009471809114-	3317.69822099258	2486.32040150129
0.4	3425.54567519250	1966.69786572870	3864.79641166332	3557.09000111348
0.6	3138.70839467361	2107.92988255149	3436.79528036171	3273.76815043390
0.8	2809.01144418753	2004.95030963129	3035.37193841507	2935.50998675200
1	2529.53719750065	1867.06603035745	2712.36017413494	2646.37565577034
2	1703.26426970762	1342.17377866110	1797.36980982439	1785.97406333194
3	1306.51205878266	1054.14238383980	1370.29969958416	1371.12464496321
4	1070.88037846248	875.407651414297	1119.28017692817	1124.38058012783
5	913.170224818724	752.947569927862	952.236981768551	959.098328367600
6	799.421979163238	663.285456429105	832.213821291695	839.825167306885
7	713.081477692586	594.496006364458	741.359954827448	749.256238821029
8	645.065128886246	539.864968916459	669.938547347491	677.887927450533
9	589.949642833404	495.311012348798	612.161080570018	620.042720953063
10	544.285555709873	458.203157638978	564.357752587681	572.107792900590
20	315.995056150252	269.968181775723	326.300576426323	332.335381382057
30	227.766653893350	195.917596686648	234.742080756795	239.607644192186
40	179.927821175569	155.421263497555	185.215317753452	189.312817218826
50	149.592155909272	129.602237301136	153.856865305570	157.413130144457
60	128.508195773696	111.587935320335	132.085762211484	135.238838760189
70	112.939595722364	98.2465781283638	116.023220823649	118.863255084605
80	100.937532358705	87.9371162402797	103.648700938058	106.237916580732
90	91.3816410807120	79.7127363334480	93.8017637512899	96.1850160031440
100	83.5801542134695	72.9871324852331	85.7664769619788	87.9772371744820
110	77.0818870288340	67.3769788098524	79.0762109609274	81.1401659657457
120	71.5795058845172	62.6206264284340	73.4132953142049	75.3506199708596
130	66.8561401086917	58.5331118136793	68.5536779122902	70.3805291085285
140	62.7542052734559	54.9798236050580	64.3346282830383	66.0641610904465
150	59.1563319369130	51.8603623420065	60.6349921135917	62.2780712486686
160	55.9732366611674	49.0982576114586	57.3626395939682	58.9283501296191
170	53.1357485959796	46.6341977136333	54.4462177359833	55.9422397474181
180	50.5894162274607	44.4214437516204	51.8295738017790	53.2624624781162
190	48.2907676094241	42.4226456342349	49.4678898005503	50.8432884297653
200	46.2046598980625	40.6075828721673	47.3249438085273	48.6477481668021

Table 4. Values of range (in g/cm²) of Bone, brain, Adipose and Blood tissues.

Energy (MeV)	Range (g/cm²) Bone	Range (g/cm²) Brain	Range (g/cm²) Adipose tissue	Range (g/cm²) Blood
0.2	1.95865E−05	1.69485E−05	1.48214E−05	1.63444E−05
0.4	6.38135E−05	5.51423E−05	4.87933E−05	5.31031E−05
0.6	0.000127342	0.000109949	9.79628E−05	0.000105797
0.8	0.000207906	0.000179406	0.000160632	0.000172532
1	0.00030409	0.000262288	0.000235732	0.000252126
2	0.000990734	0.000853359	0.00077605	0.00081916
3	0.001977046	0.001701528	0.001558083	0.001632014
4	0.003227843	0.002776418	0.00255482	0.002661459
5	0.004721142	0.004059062	0.003749286	0.003889258
6	0.006441276	0.00553595	0.005129335	0.005302429
7	0.008376242	0.007196737	0.006685634	0.006891034
8	0.01051641	0.009033123	0.008410674	0.008647104
9	0.012853796	0.011038232	0.010298215	0.010564039
10	0.015381623	0.013206227	0.012342954	0.012636236
20	0.050113792	0.042966681	0.040634008	0.041055252
30	0.100003862	0.085672045	0.081581284	0.081794454
40	0.163272251	0.139792819	0.133770461	0.133388906
50	0.238806994	0.204374028	0.196312763	0.194924636
60	0.325815608	0.278735436	0.268572225	0.265750965
70	0.423690976	0.362356137	0.350060113	0.345369827
80	0.531945932	0.454818283	0.440383243	0.433381834
90	0.650176682	0.55577564	0.539215008	0.529456142
100	0.77804041	0.664934331	0.646277592	0.633312011
110	0.915240626	0.782040251	0.761330316	0.744706749
120	1.061517106	0.906870422	0.884161622	0.863427433
130	1.216638698	1.03922681	1.014583326	0.989284999
140	1.380398017	1.178931775	1.152426381	1.122109878
150	1.552607427	1.32582462	1.297537662	1.261748698
160	1.733095938	1.479758921	1.449777476	1.408061732
170	1.921706751	1.640600429	1.609017597	1.560920884
180	2.118295299	1.808225378	1.775139689	1.720208081
190	2.32272765	1.982519124	1.948034024	1.885813961
200	2.534879192	2.163375012	2.127598427	2.057636796

Table 5. Comparison of mass stopping power (MeV cm^2/g) of This work and That of ASTAR results for Adipose tissue and Bone Cortical (ICRU-44).

$\frac{dE}{dx\rho}\left(\frac{MeV \cdot cm^2}{g}\right)$			
This work (Adipose tissue)	**A star**	**This work (Bone)**	**A star**
3317.69822099258	2.012E+03	153.009471809114-	1.440E+03
3864.79641166332	2.489E+03	1966.69786572870	1.826E+03
3436.79528036171	2.592E+03	2107.92988255149	1.939E+03
3035.37193841507	2.529E+03	2004.95030963129	1.921E+03
2712.36017413494	2.398E+03	1867.06603035745	1.844E+03
1797.36980982439	1.731E+03	1342.17377866110	1.369E+03
1370.29969958416	1.328E+03	1054.14238383980	1.062E+03
1119.28017692817	1.091E+03	875.407651414297	8.771E+02
952.236981768551	9.322E+02	752.947569927862	7.530E+02
832.213821291695	8.178E+02	663.285456429105	6.634E+02
741.359954827448	7.308E+02	594.496006364458	5.949E+02
669.938547347491	6.621E+02	539.864968916459	5.406E+02
612.161080570018	6.064E+02	495.311012348798	4.965E+02
564.357752587681	5.602E+02	458.203157638978	4.598E+02
326.300576426323	5.602E+02	269.968181775723	2.736E+02
234.742080756795	3.280E+02	195.917596686648	1.999E+02
185.215317753452	2.376E+02	155.421263497555	1.594E+02
153.856865305570	1.884E+02	129.602237301136	1.336E+02
132.085762211484	1.572E+02	111.587935320335	1.155E+02
116.023220823649	1.355E+02	98.2465781283638	1.021E+02
103.648700938058	1.195E+02	87.9371162402797	9.174E+01
93.8017637512899	1.071E+02	79.7127363334480	8.348E+01
85.7664769619788	8.930E+01	72.9871324852331	7.671E+01
79.0762109609274	-	67.3769788098524	-
73.4132953142049	7.446E+01	62.6206264284340	6.417E+01
68.5536779122902	-	58.5331118136793	-
64.3346282830383	-	54.9798236050580	-
60.6349921135917	6.424E+01	51.8603623420065	5.548E+01
57.3626395939682	-	49.0982576114586	
54.4462177359833	5.674E+01	46.6341977136333	4.909E+01
51.8295738017790	-	44.4214437516204	-
49.4678898005503	-	42.4226456342349	-
47.3249438085273	5.099E+01	40.6075828721673	4.419E+01

Table 6. Comparison of range (in g/cm^2) of Adipose tissue and bone of this work and ASTAR results.

Range (cm^2/g)			
This work (Adipose tissue)	ASTAR	This work (bone)	ASTAR
1.48214E−05	1.616E−04	1.95865E−05	2.328E−04
4.87933E−05	2.487E−04	6.38135E−05	3.530E−04
9.79628E−05	3.266E−04	0.000127342	4.582E−04
0.000160632	4.044E−04	0.000207906	5.612E−04
0.000235732	4.853E−04	0.00030409	6.672E−04
0.00077605	9.782E−04	0.000990734	1.297E−03
0.001558083	1.329E+03	0.001977046	2.134E−03
0.00255482	2.479E−03	0.003227843	3.175E−03
0.003749286	3.473E−03	0.004721142	4.409E−03
0.005129335	4.621E−03	0.006441276	5.826E−03
0.006685634	5.916E−03	0.008376242	7.419E−03
0.008410674	7.354E−03	0.01051641	9.184E−03
0.010298215	8.933E−03	0.012853796	1.111E−02
0.012342954	1.065E−02	0.015381623	1.321E−02
0.040634008	3.492E−02	0.050113792	4.250E−02
0.081581284	7.125E−02	0.100003862	8.584E−02
0.133770461	1.189E−01	0.163272251	1.422E−01
0.196312763	1.772E−01	0.238806994	2.110E−01
0.268572225	2.459E−01	0.325815608	2.918E−01
0.350060113	3.246E−01	0.423690976	3.840E−01
0.440383243	4.131E−01	0.531945932	4.875E−01
0.539215008	5.111E−01	0.650176682	6.018E−01
0.646277592	6.185E−01	0.77804041	7.268E−01
0.761330316	-	0.915240626	-
0.884161622	9.264E−01	1.061517106	1.085E+00
1.014583326	-	1.216638698	-
1.152426381	-	1.380398017	-
1.297537662	1.289E+00	1.552607427	1.505E+00
1.449777476	-	1.733095938	-
1.609017597	1.704E+00	1.921706751	1.985E+00
1.775139689	-	2.118295299	-
1.948034024	-	2.32272765	-
2.127598427	2.169E+00	2.534879192	2.522E+00

Table 7. The empirical formulae for calculating mass stopping powers.

Equation	$y = y_0 + A_1 * (1 - \exp(-x/t_1)) + A_2*(1 - \exp(-x/t_2))$
Blood	$A_1 = -547.27256 \pm 297.663$, $t_1 = 30.5067 \pm 27.86813$ $A_2 = -2879.33959 \pm 285.98521$ $t_2 = 2.74288 \pm 0.63698$ $y_0 = 3484.79465 \pm 154.41194$ $R^2 = \mathbf{0.96899}$
Bone	$A_1 = -532.03603 \pm 83.68513$, $t_1 = 24.99708 \pm 5.95676$ $A_2 = -1820.68153 \pm 76.38709$ $t_2 = 2.60151 \pm 0.26001$ $y_0 = 2406.28198 \pm 48.37597$ $R^2 = \mathbf{0.99562}$
Brain	$A_1 = -2783.67273 \pm 257.07815$, $t_1 = 2.63706 \pm 0.57406$ $A_2 = -545.29981 \pm 267.99083$ $t_2 = 29.18129 \pm 24.18423$ $y_0 = 3385.39947 \pm 142.88887$ $R^2 = \mathbf{0.97249}$
Adipose tissue	$A_1 = -3277.41059 \pm 176.80389$, $t_1 = 1.99287 \pm 0.25775$ $A_2 = -748.36646 \pm 180.02577$ $t_2 = 22.17977 \pm 9.59389$ $y_0 = 4090.93454 \pm 116.68704$ $R^2 = \mathbf{0.98946}$

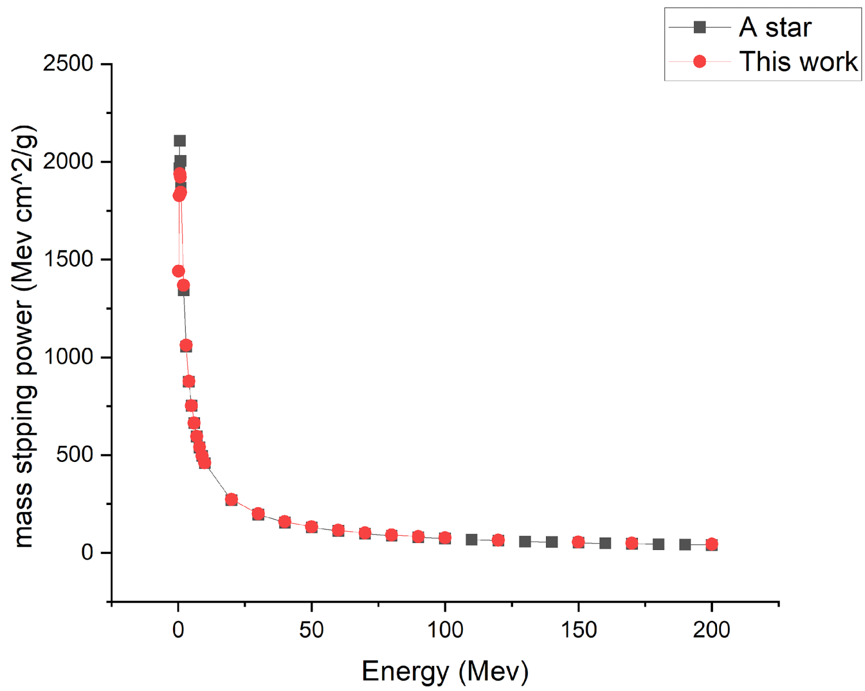

Figure 2. Mass stopping power of bone versus energy of Alpha particles.

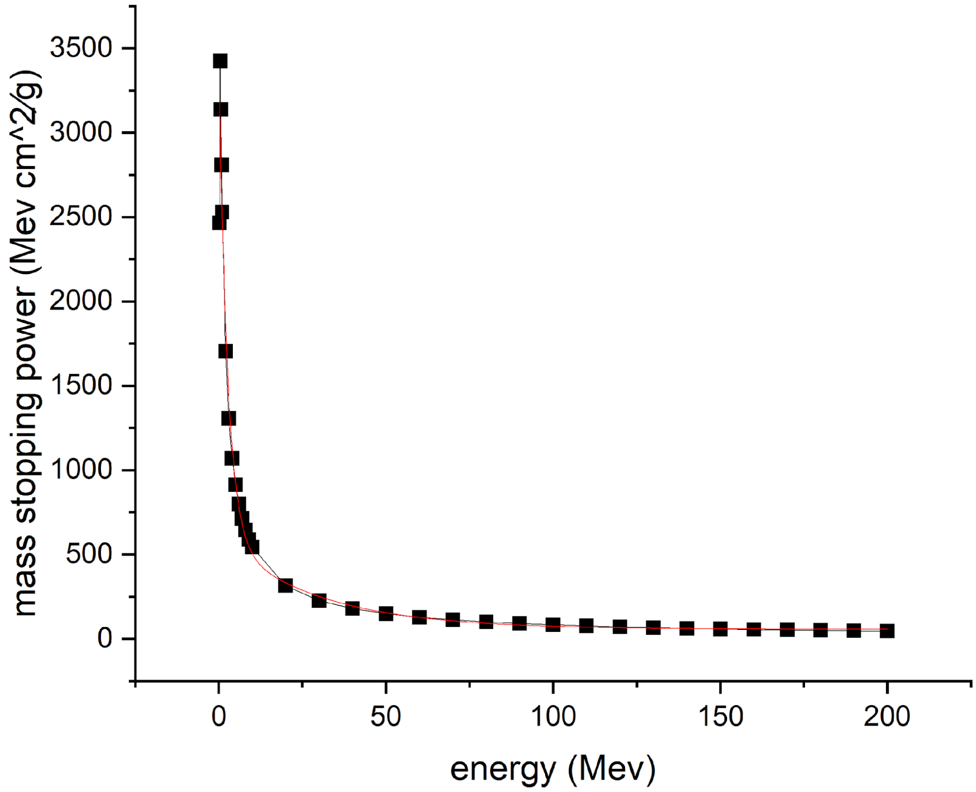

Figure 3. Mass stopping power of brain versus energy of Alpha particles.

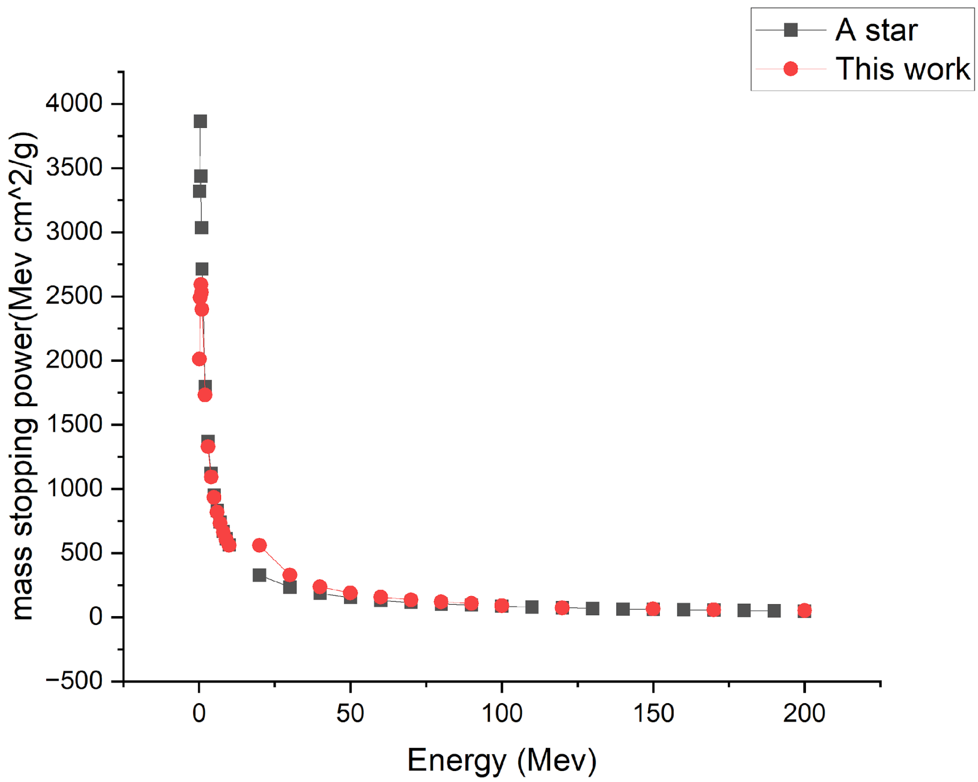

Figure 4. Mass stopping power of Adipose tissue versus energy of Alpha particles.

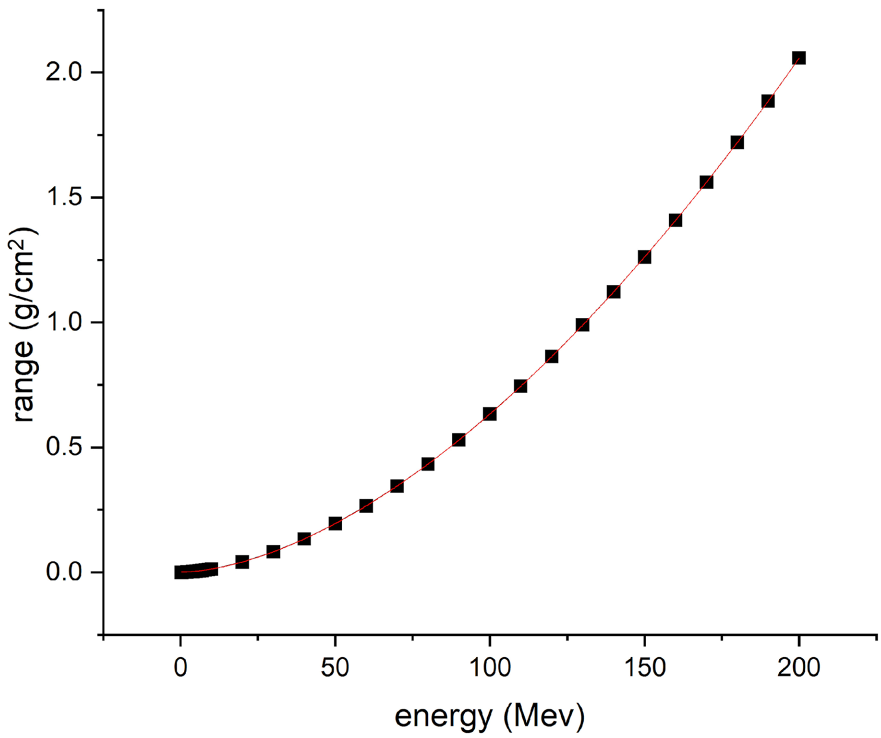

Figure 5. Range of blood versus energy of Alpha particles.

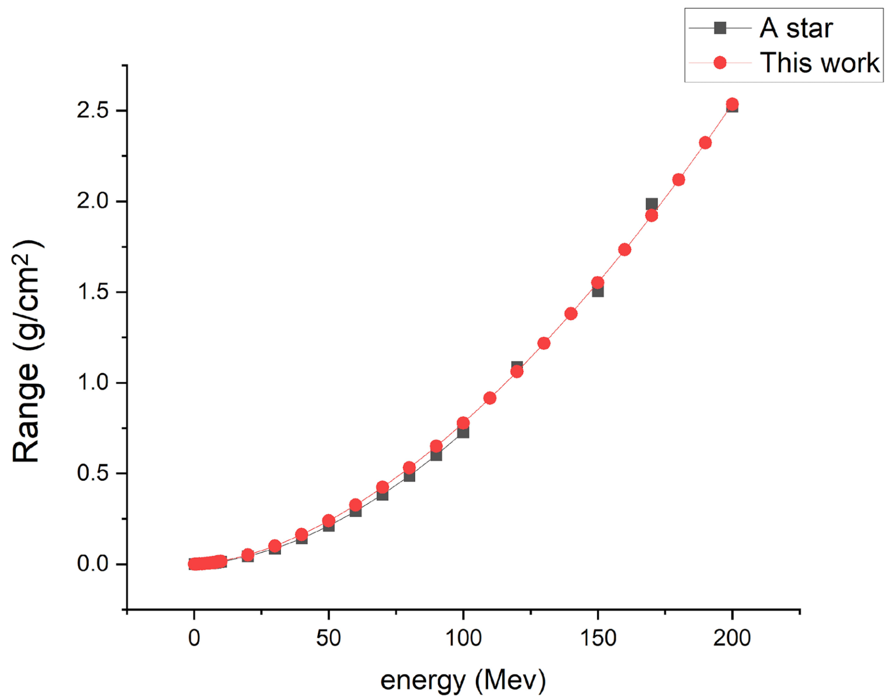

Figure 6. Range of bone versus energy of Alpha particles.

studied tissues is given in Table 8. The percentage deviation errors calculated by Equation (4) of mass stopping power for bone cortical and adipose tissues are given in Table 9 and shown in Figure 8, Figure 9.

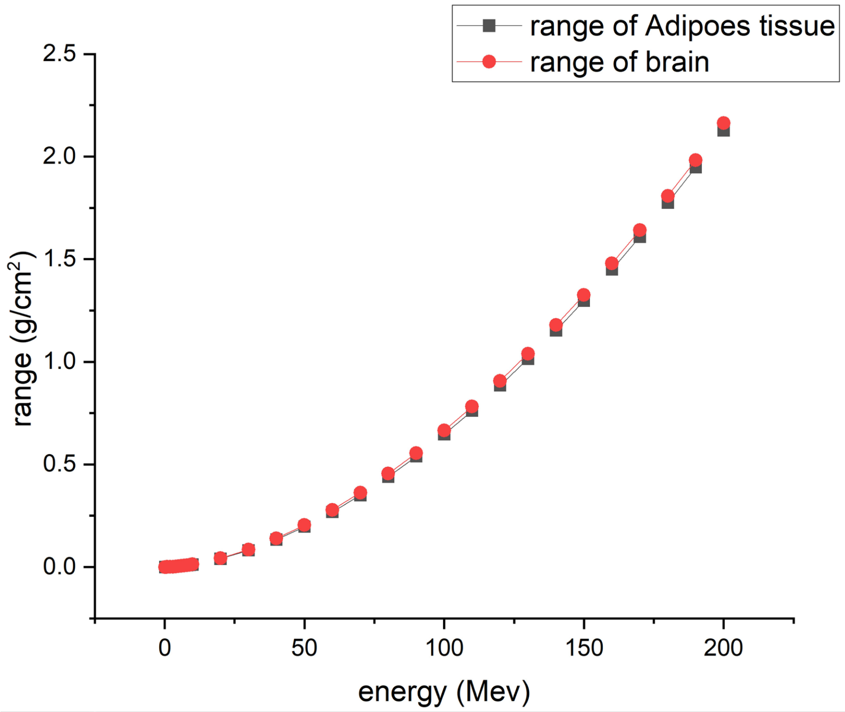

Figure 7. Range of brain and Adipose tissues versus energy of Alpha particles.

Table 8. The empirical formulae for calculating range.

Equation	$y = a \times x^b$
Blood	a = 2.52126E−4 ± 2.19507E−18 b = 1.7 ± 1.70711E−15 R^2 = 1
Bone	a = 3.0409E−4 ± 1.99208E−18 b = 1.704 ± 1.28441E−15 R^2 = 1
Brain	a = 2.62288E−4 ± 1.459E−18 b = 1.702 ± 1.09066E−15 R^2 = 1
Adipose tissue	a = 2.35732E−4 ± 9.46578E−19 b = 1.719 ± 7.87065E−16 R^2 = 1

Table 9. Percentage of deviation error of stopping power of for Adipose tissue and bone.

Energy (MeV)	Deviation (Bone)	Deviation (Adipose tissue)
0.2	-	6.49E+01
0.4	7.70525	5.53E+01
0.6	8.712217	3.26E+01
0.8	4.370136	2.00E+01
1	1.250869	1.31E+01
2	−1.95955	3.83E+00

Continued

3	−0.73989	3.19E+00
4	−0.19295	2.59E+00
5	−0.00696	2.15E+00
6	−0.01727	1.76E+00
7	−0.06791	1.44E+00
8	−0.13597	1.18E+00
9	−0.23947	9.50E−01
10	−0.34729	7.42E−01
20	−1.32742	−4.18E+01
30	−1.9922	−2.84E+01
40	−2.49607	−2.20E+01
50	−2.99234	−1.83E+01
60	−3.38707	−1.60E+01
70	−3.77416	−1.44E+01
80	−4.14528	−1.33E+01
90	−4.51277	−1.24E+01
100	−4.85317	−3.96E+00
110	-	-
120	−2.41448	−1.41E+00
130	-	-
140	-	-
150	−6.52422	−5.61E+00
160	-	-
170	−5.00265	−4.04E+00
180	-	-
190	-	-
200	−8.10685	−7.19E+00

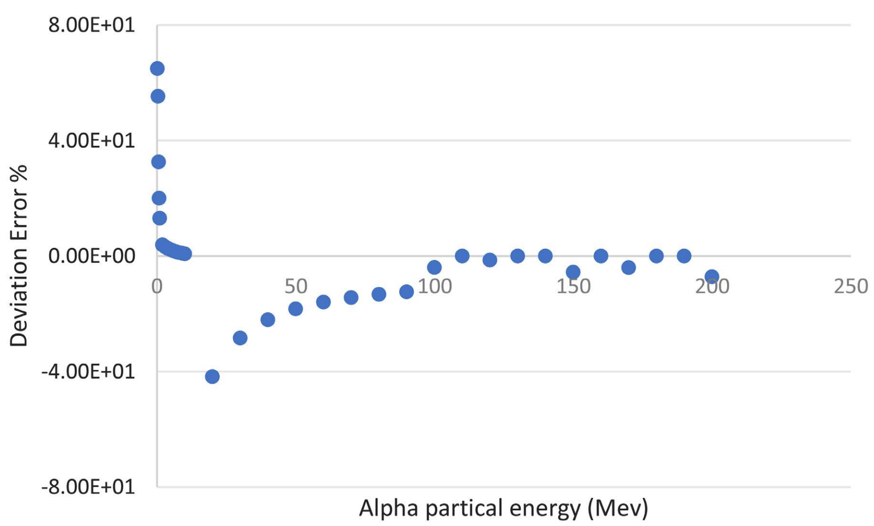

Figure 8. Deviation Error% for Adipose tissue versus energy of Alpha particles.

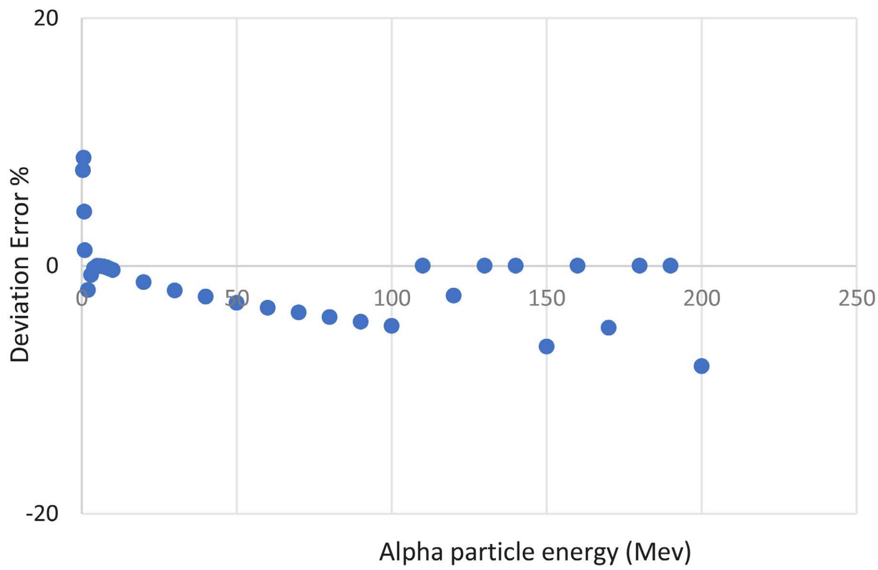

Figure 9. Deviation Error% for bone versus energy of Alpha particles.

4. Conclusions

In this study, estimates of the mass-stopping power and range of alpha particles incident on the four different human body tissues (brain, bone, adipose, and blood) in the energy range of 0.2 - 200 MeV have been made. The following findings are made:

1) As can be seen in **Figures 1-4**, all tissues under study have lower mass stopping powers as the energy of alpha particles rises. This can be explained by the fact that the rapid motion of charged particles at high energies reduces their survival time near the electron of the target material and decreases the probability of collision with it. The outcome is a slower energy transfer process, which reduces the mass-stopping power.

2) It was shown that for all investigated tissues, the alpha particle energy at 0.6 MeV had the highest mass-stopping power values.

3) As shown in **Figure 7** the range of Brain and Adipose tissues are nearly equal.

4) The ASTAR results and the current results of the mass-stopping powers of bones cortical and adipose tissues are compared, and it is found that there is good agreement between the two results. The percentage deviation error ranged between 1.2% and −8.10% for bone cortical tissue and between 13% and −7.19% for adipose tissue at the energy range of 1 - 200 MeV.

5) The empirical equations for mass-stopping power and alpha particle ranges are straightforward and cover an extensive spectrum of alpha particle energies between 0.2 and 200 MeV for all tissues under consideration. They also provide important data to people researching alpha particle therapy and shielding.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Younis, T.A.J. and Hady, F.M. (2019) Calculation of the Stopping Power of Alpha Particles and Its Range in Bone Tissue. *International Journal of Research-GRANTHAALAYAH*, **7**, 315-320. https://2u.pw/Q6URnbS
https://doi.org/10.29121/granthaalayah.v7.i4.2019.913

[2] Ahmed, I., Nowrin, H. and Dhar, H. (2020) Stopping Power and Range Calculations of Protons in Human Tissues. *Baghdad Science Journal*, **17**, 1223.
https://2u.pw/TUcLhF1
https://doi.org/10.21123/bsj.2020.17.4.1223

[3] Almutairi, A.S. and Osman, K.T. (2021). Mass Stopping Power and Range of Protons in Biological Human Body Tissues (Ovary, Lung and Breast). *International Journal of Medical Physics*, *Clinical Engineering and Radiation Oncology*, **11**, 48-59.
https://2u.pw/dpXvqfv
https://doi.org/10.4236/ijmpcero.2022.111005

[4] Sarsam, M.N. (2013) Theoretical Study of Energy Loss of Proton in Human Tissues. *Al-Qadisiyah Journal of Pure Science*, **18**. https://2u.pw/vWtRx8q

[5] Hiwa, M.Q. (2020) Stopping Power of Alpha Particles in Helium Gas. *State Technical University*, *Moscow*, **2**, 117-125. https://2u.pw/u9GoP57
https://doi.org/10.18698/1812-3368-2020-2-117-125

[6] Csete, A. (2002) Experimental Investigations of the Energy Loss of Slow Protons and Antiprotons in Matter. University of Aarhus, Aarhus.
https://2u.pw/Ay1vCwS

[7] Ahmed, S.N. (2007) Physics and Engineering of Radiation Detection. Academic Press.
https://2u.pw/DIEBNMx

[8] Mayer, M. (2003) Rutherford Backscattering Spectrometry (RBS). *Workshop on Nuclear Data for Science and Technology*: *Materials Analysis*, **34**.
https://2u.pw/5nz0UIH

[9] Peltola, J. (2003) Stopping Power for Ions and Clusters in Crystalline Solids. Chanexamp (helsinki.fi).

[10] Al-Rubaii, T.A.J.Y. (2018) Calculation of the Stopping Power and Range for Alpha Particles in Some Materials and Tissues. University of Baghdad, Baghdad.
https://2u.pw/3AtnRUr

[11] Jassim, W.N. (2015) Study of Proton Stopping Power in Be, C, Al and Cu with Energy (1-12) MeV. *International Journal of Science and Research*, **4**, 874-877.
https://2u.pw/oTzwhTt

[12] Osman, K.T. (2020) Stopping Powers of Protons in Biological Human Body Substances (Water, Tissue, Muscles and Bones). *International Journal of Novel Research in Physics Chemistry & Mathematics*, **7**, 8-12. https://2u.pw/gK2wKeN

[13] Almutairi, A.S. and Osman, K.T. (2022) Calculation of Mass Stopping Power and Range of Protons as Well as Important Radiation Quantities in Some Biological Human Bodyparts (Water, Muscle, Skeletal and Bone, Cortical). *International Journal of Medical Physics*, *Clinical Engineering and Radiation Oncology*, **11**, 99-112.
https://2u.pw/Jb9NJg7
https://doi.org/10.4236/ijmpcero.2022.112009