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Review Article

# Electron Stopping Power in Liver, Lung and Kidney Tissues: A Systematic Review

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**Abstract**:

The electron stopping power represents an essential physical factor in medical physics. This quantity is responsible for the rate of electron energy loss during passing through biological materials. Exact data on the electron stopping power play a critical role in dosimetry, treatment planning, Monte Carlo simulation, and protection against radiation. In this review, various publications on the electron stopping power in human liver, lung, and kidney tissues are presented and compared. Fifteen scientific papers dealing with the issue under discussion have been analyzed within the period from 2000 to 2026. The different types of computer simulations, including Monte Carlo simulations, Hartree-Fock-Roothaan wave functions, Bethe analytical model, dielectric-response model, and dual-energy computed tomography (DECT), are included in the review. It can be stated that the electron stopping power was significantly influenced by the density of the medium, the chemical composition of the tissue, the energy of electrons, and the density of the electrons. Lung tissue had lower stopping-power values than those of the liver and kidney due to the lower density of this material. The values of the electron stopping power were relatively high for kidney and liver. The majority of the results found in the paper were in agreement with the internationally approved databases such as NIST ESTAR.

**Keywords**: Electron Stopping Power, Human Body Tissues, Liver, Lung, Kidney, NIST ESTAR.

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## 1. Introduction:

Stopping power of electrons is dependent on several physical parameters such as incident electron energy, composition of the medium in terms of elements, mass density, and electron density. For small electron energies, collision processes are dominant in causing the loss of energy due to ionization and excitation of the atoms. As the electron energy rises, the importance of radiative losses from bremsstrahlung radiation increases, especially for high atomic number materials. Thus, accurate estimation of the electron stopping power needs inclusion of collision and radiative effects across wide energy ranges [1-3].

The electron stopping power is one of the key parameters of modern-day medical physics due to the fact that it plays an important role in determining the accuracy of the calculations of radiation doses and of treatment planning systems utilized in radiotherapy. The use of reliable stopping power data contributes to the improvement of dose distribution in target tissues while minimizing the amount of irradiation of adjacent healthy organs. Additionally, stopping power data is applied in radiation dosimetry, detector calibration,

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development of tissue-equivalent materials, and computer simulations used for quality assurance in radiation therapy [1-3].

Lungs, liver, and kidneys are some of the most important clinical organs in radiation medicine due to the fact that they often undergo radiation during diagnostics and radiotherapy. Lungs, liver, and kidneys differ in their chemical and physical properties, such as elemental composition, electron density, and mass density. The difference between the density of lung tissue compared to kidneys and livers results in differences in electron penetration depth and the behavior of electrons in these organs. Therefore, precise estimation of electron stopping power is vital for the optimization of treatment planning and dose calculation in these organs [4-6].

Despite a number of works devoted to electron stopping power in human tissues, the majority of them were focused on general soft tissue, bone, blood, or material equivalents. There is a lack of thorough reviews specifically addressing the lungs, liver, and kidney tissues. In addition to this, due to recent advances in Monte Carlo simulations, DECT, and the NIST ESTAR database, there emerged an opportunity to enhance the accuracy of stopping power calculations and radiation dose estimation at the individual organ level. Hence, an overview of the current state of the art in this sphere appears to be quite actual and may serve as a helpful guide for further investigations and clinical practice [5,6].

However, there is a shortage of integrated reviews that combine the latest advances in the field and address the question of electron stopping power in the lungs, liver, and kidneys. Thus, the objective of this review is to conduct a summary and critical analysis of the scientific literature regarding electron stopping power in lungs, liver, and kidney tissues. It will cover the physical properties of these organs, the determinants of electron stopping power, computational methods such as Monte Carlo simulations and the NIST ESTAR database, and their application for radiation dosimetry and radiotherapy.

## 2. Methodology:

The purpose of this systematic review is to find, analyze, and summarize studies that cover the issue of electron stopping power in the tissues of the liver, lung, and kidney. To accomplish this task, an exhaustive literature search in such databases as Scopus, Web of Science, PubMed, Google Scholar, and NIST ESTAR has been carried out. For the search process, a combination of such key terms as stopping power, electron stopping power, liver tissue, lung tissue, kidney tissue, Monte Carlo simulation, ESTAR, radiation dosimetry, and medical physics has been applied. The limitation of the literature search is the language of publication, that is, only English [7].

To be included in the systematic review, a study should have the following criteria: investigate the issue of electron stopping power in human liver, lung, or kidney using either experimental measurements, theoretical calculations, Monte Carlo simulation, or the NIST ESTAR database. In addition, all papers focused on unrelated tissues, duplicate papers, conference abstracts without full text, editorials, and papers with a lack of methodological information should not be included in the systematic review [8].

Data to be extracted from each paper include: publication year, authors, kind of tissue, range of electron energy, calculation/simulation method used, software/database used, main results about electron stopping power. Extracted data will be qualitatively analyzed and presented in comparative tables [9].

## 3. Theoretical Background

### 3.1 Electron Interactions with Matter

As energetic electrons penetrate the matter, they interact continuously with the atoms of the material in a process that leads to a gradual decrease in the energy of the electrons. This interaction takes place mainly via inelastic scattering of the electron from atomic electrons and leads to ionization and excitation, as well as via interactions with the atomic

nucleus and gives rise to bremsstrahlung radiation. The importance of each interaction mechanism depends on the energy of the incoming electrons and the atomic composition of the material [10].

### 3.2 Electron Stopping Power

The stopping power of electrons is a physical parameter that denotes the amount of energy lost by an electron per unit distance while passing through a substance. It describes the interaction of charged particles with matter and plays a pivotal role in the fields of radiation physics, dosimetry, and therapy planning. Stopping power is usually expressed in terms of linear stopping power (MeV/cm) and mass stopping power (MeV·cm²/g). Precise calculation of the stopping power is vital for the determination of the penetration depth of electrons, absorbed dose, and energy deposition in biological tissues. The value of the stopping power of electrons depends on the following parameters: kinetic energy of the incident electron, chemical composition of the substance, mass density, and electron density. In order to describe the process of electron transport in biological tissue, stopping power is necessary. Standard reference data provided by the National Institute of Standards and Technology (NIST) and recommendations issued by the International Commission on Radiation Units and Measurements (ICRU) are widely used as reliable sources for stopping-power calculations in radiation research and medical applications [10,11].

### 3.3 Collision and Radiative Stopping Power

Electron stopping power consists of two principal components: collision stopping power and radiative stopping power. Collision stopping power results from inelastic interactions between incident electrons and the atomic electrons of the medium, causing ionization and excitation. This component represents the dominant mechanism of energy loss in biological tissues over a wide range of electron energies. In contrast, radiative stopping power arises from the emission of bremsstrahlung radiation when electrons are deflected by the electric field of atomic nuclei. Although radiative losses increase with both electron energy and the atomic number of the absorbing material, they remain relatively small in low atomic number biological tissues such as the liver, lung, and kidney. Therefore, collision stopping power is generally the primary contributor to electron energy deposition in soft tissues used in medical dosimetry and radiotherapy [10,11,12].

### 3.4 Factors Affecting Electron Stopping Power

The electron stopping power of biological tissues is influenced by several physical and chemical factors. Among the most important are the incident electron energy, tissue density, electron density, elemental composition, and effective atomic number. As the energy of the incident electrons changes, the rate of energy loss also changes due to variations in the probability of interaction with atomic electrons. Likewise, tissues with higher mass density and electron density generally exhibit greater stopping power because they contain a larger number of atoms and electrons per unit volume. In addition, differences in elemental composition, particularly the proportions of hydrogen, carbon, nitrogen, and oxygen, contribute to variations in stopping-power values among organs such as the liver, lung, and kidney. The thorough assessment of these aspects is indispensable for exact dose computation, modeling of radiation transport processes, and optimizing the planning of radiotherapy [11,12].

### 3.5 NIST ESTAR Database

The ESTAR database developed by the National Institute of Standards and Technology (NIST) is considered to be one of the most popular databases used for estimating electron stopping powers and CSDA ranges for various types of matter. This database provides reliable values for collision, radiative, and total stopping powers at a wide spectrum of electron energies. These calculations are based on internationally recognized physical models and experiments and therefore represent a valuable

tool in radiation physics, medical dosimetry, radiotherapy treatment planning, and Monte Carlo studies. In biological tissue studies, the ESTAR database is applied to obtain information about stopping powers of tissue-equivalent materials and tissues and thus estimate electron energy losses and distribution [12,13].

### 3.6 Monte Carlo Simulation

The Monte Carlo method is among the most advanced techniques of computation in radiation physics, allowing for the simulation of particle transport and their interaction with matter. By using repeated random sampling, the technique allows reproducing the stochastic processes of radiation interaction and modeling electron transport, deposition of energy, and absorbed dose in biological tissues. Because of that, Monte Carlo simulation has become a standard in medical physics to validate dosimetric calculations and study radiation processes in complicated anatomical structures.

A wide range of Monte Carlo codes has been used in research on electron stopping power, and these codes include Geant4, EGSnrc, and PENELOPE. All those simulation tools implement physical interaction models and have been extensively validated through experiments and databases like NIST ESTAR. Therefore, Monte Carlo simulation is commonly used for estimation of stopping power, penetration range, and dose distribution in human organs such as the liver, lungs, and kidneys [14-17].

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### 3.7 Physical Characteristics of Liver, Lung, and Kidney Tissues

Liver, lungs, and kidneys are among the primary organs in the human body and have different physical properties that affect electron transport and energy deposition. These differences are mainly caused by differences in density, element composition, electron density, and effective atomic number. Since there is a strong correlation between electron stopping power and these parameters, their exact knowledge is very important for radiation dosimetry, Monte Carlo simulation, and radiotherapy treatment planning.

The liver is dense soft tissue with a density of about 1.06 g/cm³, and its chemical composition includes mainly hydrogen, carbon, nitrogen, and oxygen. The liver's relatively high density provides more electron interaction and energy deposition than in low-density tissues. On the contrary, lungs have a significantly smaller density in the range from 0.26 to 0.30 g/cm³ because of air-filled alveoli. In the lungs, the distance between electrons and their energy loss becomes much larger. The kidney's density is about the same as the liver's (about 1.05 g/cm³); however, the kidney's chemical composition includes mostly light elements that make its electron stopping power equal to that of other soft tissues. Such knowledge of physical differences of these tissues is necessary for precise determination of dose distribution and treatment planning [18-20].

## 4. Literature Review

### 4.1 Studies on Electron Stopping Power in Liver Tissue

**4.1.1** Möhler et al. (2018) experimentally estimated the problem of stopping power prediction in biological tissues using single-energy computed tomography (SECT) and dual-energy computed tomography (DECT). The experiment involved thirteen biological tissues, namely, liver, kidney, lung, brain, heart, blood, muscle, and bone. The comparison between the predicted stopping-power ratios and the reference values of the parameters showed that DECT provided much higher accuracy of predictions (with the mean absolute error of approximately 0.10%), compared to SECT. Hence, it can be concluded that DECT significantly improves the problem of stopping power estimation in biological tissues [6].

**4.1.2** Siebers et al. (2000) studied the issue of tissue-specific dose calculations through stopping power ratios of different human tissues used in

radiotherapy. According to the research results, the stopping-power ratios of liver tissue are highly similar to those of water. However, small differences in composition and electron density might influence absorbed-dose calculations. The research demonstrates that the use of tissue-specific stopping powers leads to improved precision of Monte Carlo simulations and radiotherapy treatment planning [21].

**4.1.3** Fernández-Varea et al. (2007) studied the issue of electron stopping power of some human tissues, including the liver, by calculating water-to-medium stopping-power ratios using the PENELOPE Monte Carlo code and the formalism proposed in ICRU Report 37. It was found that liver tissue exhibits highly similar stopping power ratios to those of water due to the similarity in composition and density of the two materials. Thus, the research suggests the importance of the use of tissue-specific stopping-power data to enhance the precision of the calculation of doses in radiotherapy [22].

**4.1.4** Kara et al. (2023) performed a study on the calculation of electron stopping power for liver tissue by means of Monte Carlo simulation methods and analyzed the results for GEANT4, FLUKA, and NIST ESTAR database software packages. It was found that the calculated electron stopping power for beta particles in the clinical energy range decreases with increasing particle energy. Even though the tendencies in all three computer codes were the same, small discrepancies occurred because of the different physical interaction models used in these codes. It was concluded that GEANT4 provided the best approximation of the results from the NIST ESTAR database, which proves the accuracy of its use for calculating stopping power and estimating radiation dose in liver tissue [23].

**4.1.5** Hussein et al. (2023) estimated the electron stopping power of the main elements forming human body tissues by means of the Bethe formula and the NIST ESTAR code within the electron energy range of 0.01-1000 MeV. They calculated the values of collisional and radiative stopping powers for several biologically important elements such as hydrogen, carbon, nitrogen, oxygen, sodium, phosphorus, sulfur, chlorine, potassium, calcium, iron, and iodine. The results obtained by means of the Bethe formula showed high agreement with the NIST ESTAR database and ICRU Report 37. Moreover, the authors presented a semi-empirical equation for the total electron stopping power estimation [24].

**Table 1. Summary of Studies on Electron Stopping Power in Liver Tissue**

| No. | Author(s) and Year | Method/ Approach | Energy Range | Main Focus | Key Finding Related to Liver Tissue |
|---|---|---|---|---|---|
| **1.** | Möhler et al. (2018) [6]. | Single-energy CT (SECT) and dual-energy CT (DECT) | - | Stopping power prediction in multiple human tissues, including liver | DECT provided significantly higher accuracy than SECT, with a mean absolute error of approximately 0.10% for liver tissue. |
| **2.** | Siebers et al. (2000) [21]. | Monte Carlo simulations (EGS4 code) with tissue-specific compositions | 0.025 - 20 MeV | Tissue-specific dose calculations and stopping-power ratios | Liver tissue shows stopping-power values very close to water. Small differences in elemental composition and electron density can influence absorbed-dose calculations. |
| **3.** | Fernández-Varea et al. (2007) [22]. | PENELOPE Monte Carlo simulation and water -to-medium stopping power ratios (ICRU Report37 | 0.01-1000MeV | Electron stopping power in several human tissues, including liver | Liver stopping power ratios are very close to water across the energy range due to similar elemental composition and density. Results improve the accuracy of dose calculations in radiotherapy. |
| **4.** | Kara et al. (2023) [23]. | Monte Carlo simulations (GEANT4, FLUKA) and comparison with NIST ESTAR | 0.01 - 1000 MeV | Electron stopping power in liver tissue among other tissues) | The calculated electron stopping power in liver tissue decreased with increasing energy. GEANT4 showed the closest agreement with NIST ESTAR reference data |
| **5.** | Hussein et al. (2023) [24]. | Bethe formula and NIST ESTAR database (for major components of tissues, including liver) | 0.01 - 1000 MeV | Electron stopping power of main components in human tissues. | Calculated stopping powers for liver components showed excellent agreement with NIST ESTAR data over the whole energy range. |

**Abbreviations**: Penelope: Monte Carlo Code for Electron and Photon Transport; ICRU: International Commission on Radiation Units and Measurement; EGS4: Monte Carlo Code for Electron and Photon Transport (Electron Gamma Shower version 4); GEANT4: Monte Carlo Particle Transport Toolkit; FLUKA: Monte Carlo Particle Transport Code; NIST ESTAR: NIST Electron Stopping-Power and Range Data Table; AAPM TG-21: American Association of Physicists in Medicine Task Group No. 21.

#### 4.1.6 Summary of Liver Tissue Studies

It appears from the analyses presented above that the stopping power of electrons in hepatic tissue mainly depends on electron energy, the composition of the tissue, and the method used in computations. The majority of studies used Monte Carlo simulations, theoretical calculations based on the Bethe formula, and comparisons with the NIST ESTAR database to estimate stopping powers. All these approaches produced consistent results compared to the reference data, thus demonstrating the efficiency of these methods for estimating electron dosimetry. Additionally, due to recent progress in computer calculations, the accuracy of stopping power estimation improved, thus emphasizing their practical significance in treatment planning and radiation protection. In general, it can be stated that stopping power values are crucial for accurate dosimetry of liver tissue, but more experiments are needed for verification of the theoretical data.

### 4.2 Studies on Electron Stopping Power in Lung Tissue

**4.2.1** Tan and Liu (2013) systematically calculated the stopping powers and inelastic mean free paths of electrons in eleven types of human tissues over the energy range of 20 eV–20 keV using a dielectric-response model with the Born–Ochkur exchange correction. The investigated tissues included the liver, lung, kidney, muscle, adipose tissue, brain, and several other biological tissues. The calculated optical energy-loss functions satisfied the dielectric-response f-sum rule, and the estimated mean excitation energies agreed well with Bragg-rule predictions. Furthermore, the calculated stopping-power values were compared with liquid water and polymethylmethacrylate (PMMA), demonstrating good consistency and confirming the applicability of the proposed model for radiotherapy dosimetry and radiation–tissue interaction studies [25].

**4.2.2** Yalçın et al. (2017) investigated electron stopping power and continuous slowing down approximation (CSDA) ranges in several human tissues using Hartree–Fock–Roothaan wave functions. The investigated tissues included lung, intestine, skin, larynx, breast, bladder, prostate, and ovary over a wide electron energy range. The calculated stopping-power values were analyzed using effective approximation methods and compared with reference data. The results show strong agreement with existing values and demonstrate that the values of stopping power in pulmonary tissue are lower than those in other more dense tissue types due to their lower density and mean excitation energies. The authors emphasize the importance of accurate calculations of the stopping powers of different types of human tissue [26].

**4.2.3** Usta and Tufan (2017) performed calculations on electron stopping power and CSDA range for various human tissues, including pulmonary tissue, using the Hartree-Fock-Roothaan (HFR) wave-function technique. Calculations covered a wide range of electron energies and were verified with reference databases such as ICRU 44, ICRU 46, SRIM, JANIS, and CASP. For the case of lung tissue, the obtained values of the stopping power showed good agreement with the SRIM database at low and medium energies; thus, the HFR method can be used for reliable calculation of the electron stopping power in biological tissues [27].

**4.2.4** Mahdi (2019) studied the total mass stopping power of electrons in certain human body tissues in the energy range from 0.01 to 1000 MeV. This research included computation of the collision, radiative, and total mass stopping powers for the lung tissue and comparison of these values with the NIST ESTAR database. Good agreement was observed between the calculated and reference values, where the maximum percentage error did not exceed 0.3% for the lung tissue. Furthermore, it was found that at lower energies, the collision stopping power prevails, while at higher ones, the radiative stopping power becomes significant. Thus, the theoretical calculations provide reliable information

on the stopping power of electrons in biological tissues, and the NIST ESTAR database can be used as a reference source for estimation of the stopping power in electron dosimetry [28].

**4.2.5** Imad (2024) performed a theoretical investigation of the radiation stopping power of electrons in various human tissues, including lung tissue, in the energy range of 10-1000 MeV. Stopping power values were calculated based on the Berger-Seltzer approximation and compared with the reference data from the NIST ESTAR database. It has been shown that good agreement is observed between the calculated and ESTAR values; moreover, the significant energy dependence of stopping power in the case of lung tissue is noted due to the relatively low density of the tissue. Therefore, this study demonstrates that reliable stopping power calculations are important for improvement of electron dosimetry and radiotherapy treatment planning in lung tissue [29].

**4.2.6** Bito et al. (2025) evaluated the electron mass stopping power in different human tissues based on the modified Bethe-Bloch formalism of collisional stopping power and analytical calculation of radiative contribution. The tested tissues included lung, skin, blood, fat, soft tissue, eye lens, breast gland, cartilage, lymph glands, and bone. The calculated values of the stopping powers were compared with the available reference values and found to have a high degree of consistency over a wide range of electron energies. The study indicated that the lung tissue is characterized by the low mass stopping power as compared with dense tissues because of the low physical density and elemental composition of the lung [30].

### 4.2.7 Summary of Lung Tissue Studies

From the literature reviewed, it is apparent that there is extensive investigation on the electron stopping power of lung tissue via theoretical models and Monte Carlo simulation techniques spanning a wide range of electron energies. Various theoretical methods have been used in the evaluation of electron stopping power in lung tissue, such as the Bethe model, the Berger-Seltzer theory, dielectric response theories, Hartree-Fock-Roothaan wave functions, and Bethe-Bloch theories modified among others. Although different methods have been utilized, there is remarkable agreement between the calculated values of the stopping power and NIST ESTAR database values as well as other reported databases. Most studies reveal that the stopping powers of the lung tissue are relatively low when compared to those of denser tissues due to their lower densities and composition.

**Table 2. Summary of Studies on Electron Stopping Power in Lung Tissue**

| No. | Author(s) and Year | Method/ Approach | Energy Range | Main Focus | Key Finding Related to Lung Tissue |
|---|---|---|---|---|---|
| **1.** | Tan and Liu (2013) [25]. | Dielectric-response model with Born-Ochkur exchange correction | 20 eV - 20 keV | Stopping powers and inelastic mean free paths in 11 human tissues | The calculated stopping powers for lung tissue agreed well with theoretical reference data and satisfied the dielectric-response model requirements. |
| **2.** | Yalçın et al. (2017) [26]. | Hartree-Fock-Roothaan wave functions | Wide electron energy range | Stopping power and CSDA range in several human tissues | Lung tissue exhibited lower stopping power values than denser tissues. The calculated results showed good agreement with reference data. |
| **3.** | Usta and Tufan (2017) [27]. | Hartree–Fock–Roothaan (HFR) wave-function method | 1 MeV – 1 GeV | Electron stopping power and CSDA range calculations in human tissues. | The calculated electron stopping power values for lung tissue showed good agreement with SRIM reference data, demonstrating the reliability of the HFR model for electron stopping-power calculations. |
| **4.** | Mahdi (2019) [28]. | Bethe formula and NIST ESTAR database | 0.01 - 1000 MeV | Total mass stopping power of electrons in lung, skin, and urea | The calculated total mass stopping power for lung tissue showed excellent agreement with NIST ESTAR, with a maximum percentage error of about 0.27%. |
| **5.** | Imad (2024) [29]. | Berger-Seltzer equation and theoretical calculations | 0.01 - 1000 MeV | Radiation stopping power of electrons in several human tissues | Lung tissue exhibited lower radiation stopping power than denser tissues. The calculated values agreed well with reference data, confirming the applicability of the theoretical model. |
| **6.** | Bito et al. (2025) [30]. | Modified Bethe-Bloch equation and analytical calculations | 0.01 - 1000 MeV | Electron mass stopping power in different human tissues. | Lung tissue showed lower mass stopping power because of its lower density and elemental composition. The calculated values agreed well with published reference data. |

### 4.3 Studies on Electron Stopping Power in Kidney Tissue

**4.3.1** Möhler et al. (2018) experimentally evaluated stopping power ratio prediction in thirteen biological tissues, including kidney tissue, by comparing single-energy computed tomography (SECT) and dual-energy computed tomography (DECT) with experimentally measured reference values. Five kidney samples were analyzed as part of the biological tissue dataset. The results showed that DECT predicted the stopping-power ratio of kidney tissue with excellent accuracy, achieving an overall mean absolute error of approximately 0.10%, whereas SECT exhibited considerably larger prediction errors. The study concluded that DECT provides a highly reliable method for tissue-specific stopping power estimation and can reduce range uncertainties in particle therapy involving kidney tissue [6].

**4.3.2** Siebers et al. (2000) investigated tissue-specific stopping power ratios using Monte Carlo simulations (EGS4) for several biological tissues, including kidney tissue. The study evaluated the influence of tissue elemental composition and electron density on absorbed-dose calculations over an energy range of approximately 0.025–20 MeV. The results demonstrated that the stopping-power ratio of kidney tissue was very close to that of water, with only minor variations caused by differences in elemental composition. These findings indicated that accurate tissue-specific stopping-power data improve dose calculation accuracy in radiotherapy, particularly when heterogeneous tissues such as the kidney are considered [21].

**4.3.3** Tan and Liu (2013) calculated the electron stopping powers and inelastic mean free paths for 11 different human tissues, including kidney tissue, using the dielectric-response model with the Born–Ochkur exchange correction over an energy range of 20 eV to 20 keV. For kidney tissue, the calculated stopping-power values showed excellent agreement with theoretical reference data and satisfied the dielectric-response f-sum rule. The study demonstrated that the adopted theoretical model accurately predicts electron energy loss in kidney tissue, making it suitable for applications in radiation dosimetry, radiation transport, and medical physics [25].

**4.3.4** Dlshad and Rashid (2026) investigated the stopping powers and continuous slowing down approximation (CSDA) ranges of positrons and electrons in human kidney, lung, and thyroid tissues. The study employed a modified Bethe–Bloch equation together with analytical calculations to evaluate stopping powers over an energy range of 100 eV to 1 MeV. The calculated results for kidney tissue were compared with the Penelope 2012 Monte Carlo code and showed good agreement across the investigated energy range. The study demonstrated that the stopping power of electrons decreases with increasing energy, while the CSDA range increases accordingly. These findings support the applicability of the modified Bethe–Bloch approach for electron transport and radiation dosimetry in kidney tissue [31].

#### 4.3.5 Summary of Kidney Tissue Studies

As can be gleaned from the evaluated studies, the electron stopping power of renal tissues has been analyzed using various types of computational methods, such as Monte Carlo modeling, analytical calculations, and stopping power ratio of tissue methods, among others. Though the number of studies on the subject is fewer compared to the body of literature on pulmonary tissue, the findings always tend to conform to the existing reference sources and software simulations. It has been found that the stopping power of renal tissues is highly dependent on the elemental composition, density, and electron density of the organ. The implication is that the current computation techniques for finding electron stopping power are reliable for kidney tissues.

**Table 3. Summary of Studies on Electron Stopping Power in Kidney Tissue**

| No. | Author(s) and Year | Method/ Approach | Energy Range | Main Focus | Key Finding Related to Kidney Tissue |
|---|---|---|---|---|---|
| **1.** | Möhler et al. (2018) [6]. | Single-energy CT (SECT) and Dual-energy CT (DECT) | - | Experimental verification of stopping-power ratio prediction in biological tissues | DECT predicted the stopping power ratio of kidney tissue with significantly higher accuracy than SECT, achieving a mean absolute error of approximately 0.10%. |
| **2.** | Siebers et al. (2000) [21]. | Monte Carlo simulations (EGS4) with tissue-specific compositions | 0.025 - 20 MeV | Tissue-specific dose calculations and stopping power ratios | Kidney tissue exhibited stopping power ratios very close to water. Minor differences in elemental composition and electron density affected absorbed-dose calculations, emphasizing the importance of tissue-specific stopping-power data. |
| **3.** | Tan and Liu (2013) [25]. | Dielectric-response model with Born-Ochkur exchange correction | 20 eV -20 KeV | Stopping powers and inelastic mean free paths in 11 human tissues including kidney | The calculated stopping powers for kidney tissue showed excellent agreement with theoretical reference data and satisfied the dielectric-response f-sum rule, demonstrating the reliability of the applied model. |
| **4.** | DIshad and Rashid (2026) [31]. | Modified Bethe-Bloch equation and comparison with PENELOPE 2012 | 100 eV - 1 MeV | Stopping powers and CSDA ranges of electrons and positrons in kidney, lung, and thyroid tissues | The calculated electron stopping powers for kidney tissue agreed well with PENELOPE 2012.<br>Electron stopping power decreased with increasing energy, whereas the CSDA range increased accordingly. |

### 4.4 Comparative Discussion of Electron Stopping Power in Lung, Liver, and Kidney Tissues

According to the reviewed research works, electron stopping power differs in the lung, liver, and kidney tissues due to the variations in their physical density, elemental composition, and effective atomic number. In particular, lung tissues demonstrate the smallest electron stopping power values because of their relatively small density and a large amount of air; liver and kidney tissues have larger values of electron stopping power owing to their increased mass density and more compact elemental composition. By means of applying various methods of calculation, including Monte Carlo simulations, the modified Bethe-Bloch formula, the Berger-Seltzer approach, and Hartree-Fock-Roothaan wave functions, researchers receive reliable results in accordance with existing databases like NIST ESTAR.

Based on the results of the comparison of the reviewed articles, one can conclude that the influence of tissue composition on the values of electron stopping power is much more significant than that of the type of the considered tissue. While all of the analyzed organs belong to different systems of an organism, the values of electron stopping power were mainly determined by the elements' composition, electron density, and mass density. Therefore, the computation methods reflecting these values provide results that are consistent with experiments.

All considered articles showed that there is a difference between electron stopping powers in lung, liver, and kidney tissues due to different physical density, element composition, and effective atomic numbers. In general, electron stopping power was the lowest for lung tissues, which was explained by their lower physical density and the presence of much air. The other tissues had higher values of the parameter, as they had higher mass density and a more compact element composition. All authors used various computational methods – from Monte Carlo simulation, modified Bethe–Bloch formula, Berger–Seltzer formula to Hartree–Fock–Roothaan wave function – but all of them showed good concordance with the NIST ESTAR reference database.

Comparison of the reviewed papers allowed us to conclude that tissue composition matters more than type of tissue when one wants to find out electron stopping power values. Despite the fact that the organs were different by belonging to different physiological systems, they had similar electron stopping power values, depending mostly on element composition, electron density, and mass density. Thus, it can be concluded that computational models, which are able to provide an accurate description of these factors, show good agreement with experimental or reference data.

## 5. Conclusion:

This review highlights the comparison between recent studies of electron stopping power in human tissue comprising lungs, liver, and kidneys. These studies reveal that electron stopping power mainly depends on tissue density, composition of elements, and electron density in tissues. While several calculation techniques have been used, including analytical and Monte Carlo simulation techniques, most results are consistent with the NIST ESTAR database, thus validating the above-mentioned methodologies.

Comparison across different human tissues reveals that lungs have a lower electron stopping power compared to liver and kidneys because of lower density, while liver and kidney have higher stopping power values because of dense tissue structure. This finding suggests the significance of having precise values of stopping power in tissues in the context of radiation dosimetry, treatment planning, radiation protection, and Monte Carlo medical physics applications.

Future research needs to focus on improving computation techniques using advanced computational models, updated tissue composition

information, and applying to other human tissues and a wide energy range.

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