New Method for Range Calculation Based on Empirical Models in Radiotherapy or Proton Therapy in Liquid Water in Hemodialysis Patients with Kidney Cancer

جامعــة الحسن الثاني بالدار البيضاء
UNIVERSITÉ HASSAN II DE CASABLANCA

H. Inchaouh [(1)], M. Farh [(1)], E.H. Tahri [(1)] ; G.Medkouri [(2)] ; S. Mekouar[(3)] M.Krim[4], J.Inchaouh[5*], I. Ghazi[5]

[(1)] Laboratoire de physiopathologie et de génétique moléculaire, Faculté des sciences Ben Msik, Université Hassan II de Casablanca. Maroc
[(2)] Centre de néphrologie, CHU Ibn Rochd de Casablanca, Université Hassan II de Casablanca.
[(3)] Centre des maladies rénales et hémodialyse Al Amine Casablanca
(4) Laboratory of sciences and health technologies, BP 555,26000, Settat,Hassan first University of settat,high institute of Haealth Sciences3
(5) Laboratoir de physique et de la matière Condensée , Faculté des sciences Ben Msik, Université Hassan II de Casablanca. Maroc
* professeur associé Corresponding authors Houda Inchaouh : inchaouh@gmail.com

Abstract: In patients with kidney cancer or hemodialysis, direct ionization and excitation of biomolecular electrons of DNA or by indirect chemical reaction of free radical products with DNA usually leads to quite significant biological damage that can lead to death.

In this work, we conducted a comprehensive study focusing on comparing three types of particles: photons and electrons in radiotherapy, and protons in proton therapy. The initial calculation results clearly reveal the differences in the interaction of beams of energetic photons, electrons, or ionic protons with the softest tissues of the kidney, which contain more than 80% water. Proton collisions with water molecules were evaluated based on ionization, excitation, and charge change processes. These results provide a basis for estimating the Bragg peak in biological matter composed of H2O and DNA.

In a second step, we followed in hemodialysis patients; the albumin protein, the Body Mass Index (BMI) are parameters to be monitored more closely. In Morocco, this problem is real and awareness is needed to inform patients about their diet. Indeed, a preliminary reduced study has been established on this subject, namely phosphocalcic disorders in hemodialysis in a private dialysis center in Casablanca and this on a sample of 68 patients. At the end of this study, the proportion of patients with well-controlled phosphoremia according to KDIGO 2 recommendations is 54.41%, and 33.83% of patients have hyperphosphatemia while only 11.76% have hypophosphatemia, with an average of 50.49 mg/l, we found a large population with hypocalcemia and 57.35% who complied with vitamin D standards, while 40% of patients were lower.

Through this work based on the biological parameters that we present, we will emphasize the importance of medical follow-up and early evaluation of the phosphocalcic profile and the biological status of patients receiving regular doses of irradiation. In order to slow the progression of chronic kidney disease (CKD) and improve the quality of life in these patients, we plan to first develop an exploitation sheet based on multiple biological data grouping together energy and protein intake, as well as salt, phosphorus and potassium intake that can induce dangerous comorbidities.

Keywords: Bragg peak, liquid water, stopping cross sections, biological, : Radiotherapy; IRC Proton Therapy - Albumin - Calcium - Phosphorus - Nutrition

First step :

In this study, we used Monte Carlo methods which refer to a family of algorithmic methods aimed at calculating an approximate numerical value using random methods, **[1].** These methods are currently among the most accurate methods for determining the dose deposited in the tumor organ and even in organs at risk. Dose calculations were performed using the code GEANT4, version 10.04.p03. This code is a software interface for the Monte Carlo method to simulate the movement of particles through matter. **[2].** To calculate the dose spent in the kidney and organs at risk, we have developed and finalized the modeling of the male pelvic area that we have already started in the form of a mathematical phantom with real dimensions and real clinical data **[3].** This area is composed of the right kidney and the left kidney, as shown in **Figure 1**.

The energy deposited from the beams in a biological medium is the result of essential projectile collisions - charge exchange, excitation, ionization, elastic and inelastic collisions - with target molecules **Figure 2**. The quantity of energy deposited represented by the stopping power is considered to be a very important parameter for characterizing and studying the biological effect caused in the irradiated environment. The position of the Bragg peak is the most requested parameter to treat biological damage.

Several theoretical and semi-empirical works **[4]** are being studied to calculate the stopping power – position of the Bragg peak of proton beams with water and DNA. The Molina approach **[1],** which used the Monte Carlo method, models the stopping power as a function of the target depth in liquid water for proton beams with an incident energy ranging from 0.5 to 300 MeV **Figure 3, 4 and 5** illustrating the deposited dose in nGy respectively for protons, electrons and photons.

Figure1: Structure of the kidney in geant 4 [3]

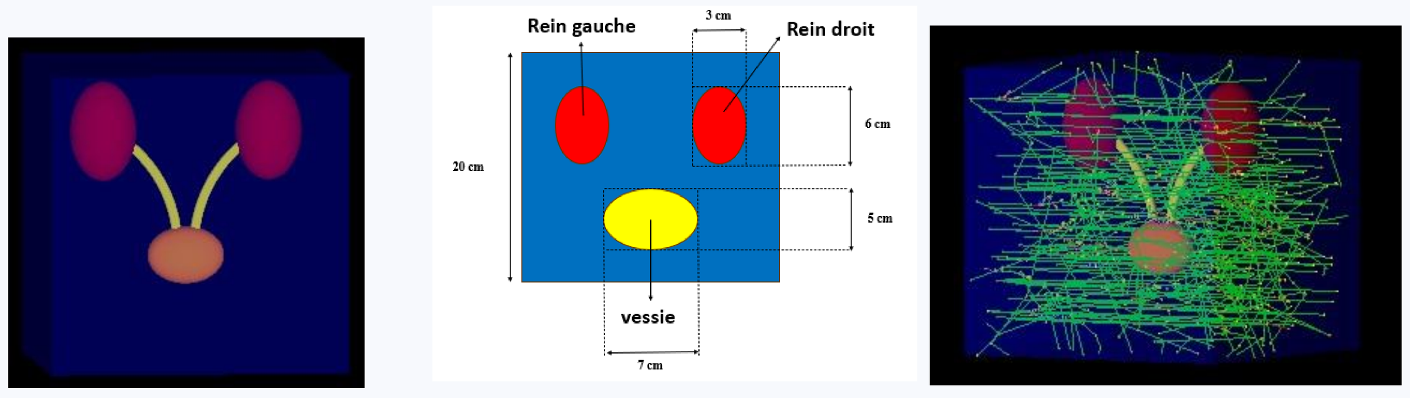
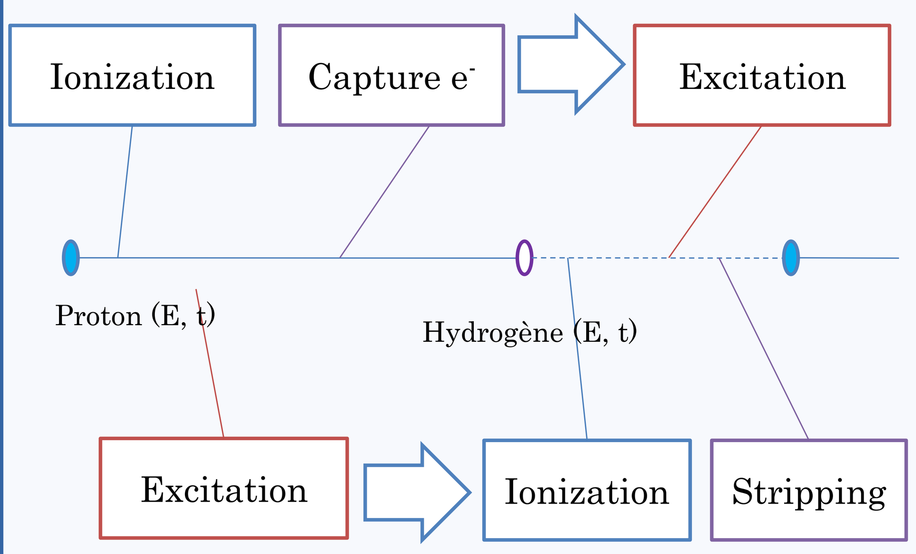
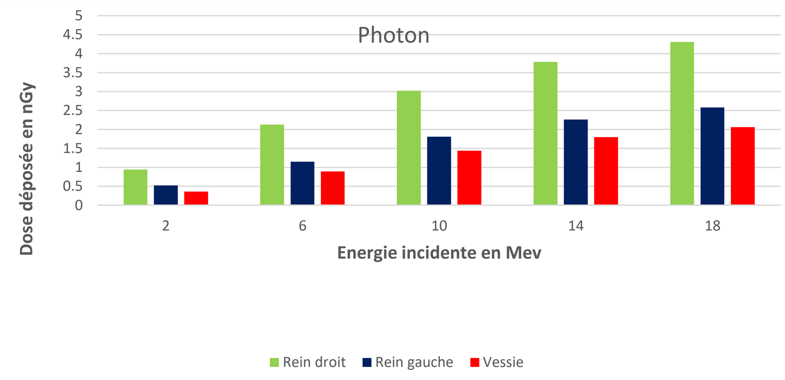


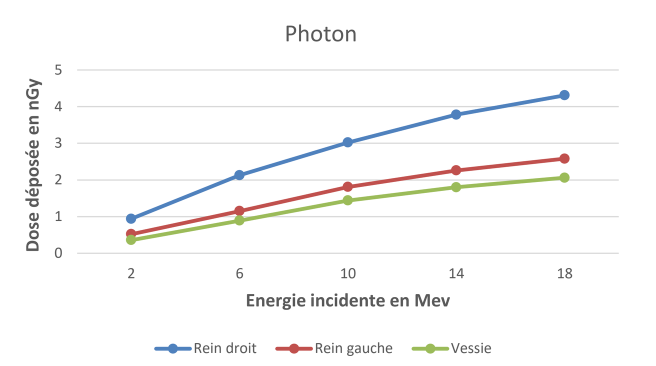
Figure 2 : Physical processes of interaction proton beams with water (2)



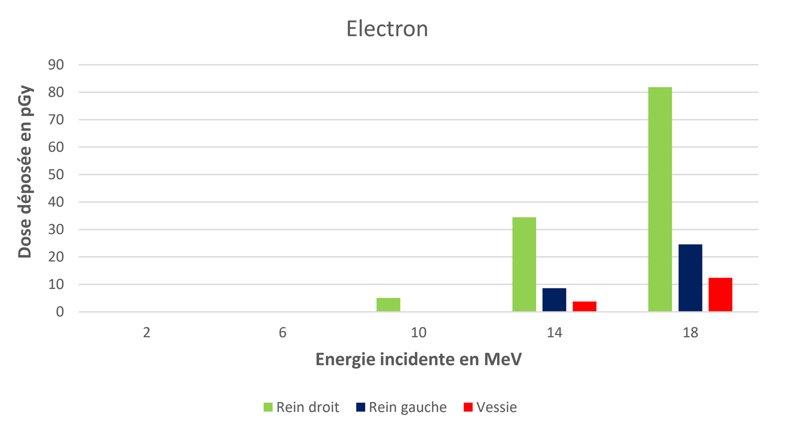
Ionization by proton	$p + H_2O \rightarrow p + H_2O^+ + e^-$
Excitation by proton	$p + H_2O \rightarrow p + H_2O^*$
Electron capture	$p + H_2O \rightarrow H^* + H_2O^+$
Electron loss	$H + H_2O \rightarrow p + e^- + H_2O$
Ionization byl'hydrogène	$H + H_2O \rightarrow H + H_2O^+ + e^-$
Excitation by l'hydrogène	$H + H_2O \rightarrow H + H_2O^*$
stripping	$H + H_2O \rightarrow P + H_2O + e^-$

Photon	Rein droit	Rein gauche	Vessie
2 MeV	0,94 nGy	0,54 nGy	0,36 nGy
6 MeV	2,13 nGy	1,15 nGy	0,89 nGy
10 MeV	3,02 nGy	1,81 nGy	1,44 nGy
14 MeV	3,78 nGy	2,26 nGy	1,80 nGy
18 MeV	4,31 nGy	2,58 nGy	2,06 nGy





Electron	Rein droit	Rein gauche	Vessie
2 MeV	0 pGy	0 pGy	0 pGy
6 MeV	0 pGy	0 pGy	0 pGy
10 MeV	5,12 pGy	0 pGy	0 pGy
14 MeV	34,45 pGy	8,61 pGy	3,79 pGy
18 MeV	81,85 pGy	24,55 pGy	12,38 pGy



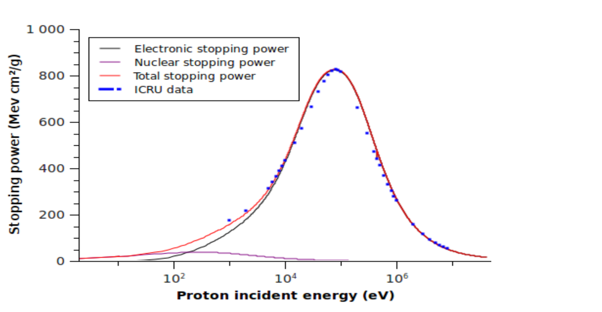
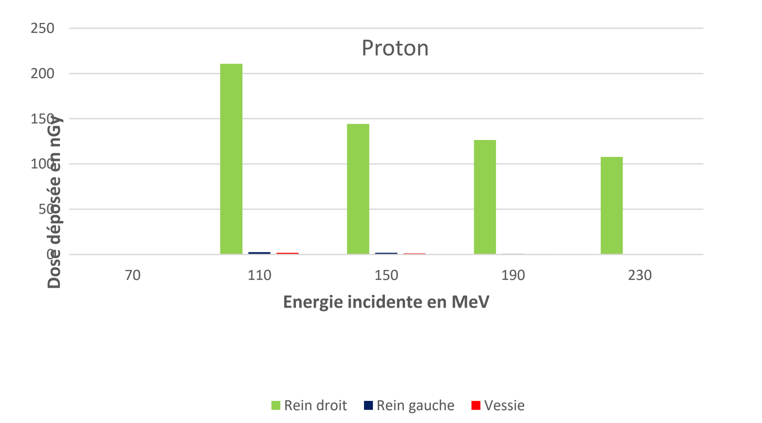


Fig 4 : The total stopping power S_T, S_E electronic stopping power and a nuclear stopping power S_N proton in liquid water according to the energy of the incident proton **(ref 5)**

Proton	Rein droit	Rein gauche	Vessie
70 MeV	0 nGy	0 nGy	0 nGy
110 MeV	210,66 nGy	2,52 nGy	1,86 nGy
150 MeV	144,18 nGy	1,87 nGy	1,12 nGy
190 MeV	126,55 nGy	0,62 nGy	0,37 nGy
230 MeV	107,65 nGy	0,25 nGy	0,13 nGy



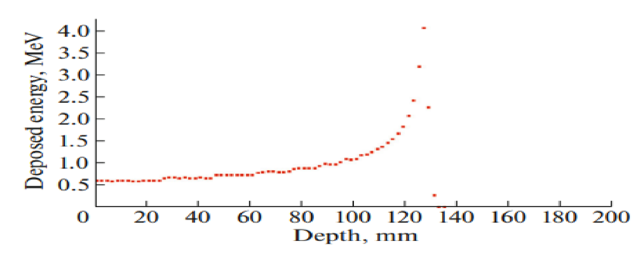
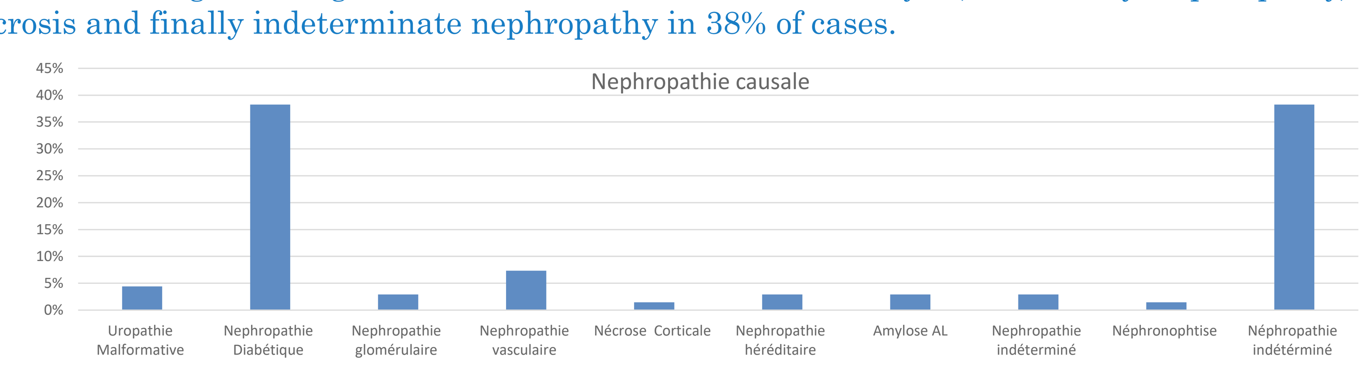


Fig. 3. Representative curve of the Bragg peak for an incident energy of 133 MeV.

Step Two:

A descriptive study was established in a hemodialysis Center Casablanca (Morocco) for patients (68 patients) with end-stage chronic kidney disease. An exploitation sheet has been drawn up in an informative manner in order to determine the levels of the various agents involved in mineral and bone disorders according to the latest biological assessment carried out. The impact of the pathophysiological mechanisms at the origin of CKD mineral disorders plays a decisive role on the skeleton and the vascular wall, which requires regular and continuous monitoring of the biological elements of the dialysis patient. a follow-up of the different biological elements specifying the design of the study and the collection of data, the criteria of inclusion and preliminary exclusion over a period of dialysis of more than 6 months has been initiated and we intend to increase this sample in the analytical part to have sufficient statistics to analyze the clinical aspects, biological, therapeutic and evolutionary of hemodialysis patients who suffer from mineral and bone disorders. This preliminary study highlights the high prevalence of mineral and bone disorders in chronic hemodialysis, hence the interest of prevention, which starts with early management of chronic kidney disease and effective dialysis. We give as an indication (Figure 6) the spectrum of causal nephropathy in this series, of patients 38% of the population had diabetic nephropathy, vascular nephropathy represented about 8% and glomerular was 3%.

The causalities causing end-stage chronic renal disease on hemodialysis, hereditary nephropathy, malforvative uropathies, Al amyloidosis, nephrophthisis and cortical necrosis and finally indeterminate nephropathy in 38% of cases.



Discussion :

According to the results observed, a significant trend emerges:

As the energy of the photons increases, so does the absorbed radiation dose. This increase is observed both in the right kidney, identified as the tumor organ, and in the left kidney and bladder, identified as organs at risk. This direct relationship between the energy of the photons and the dose of radiation deposited sheds light on the fundamental physical characteristics of photons as massless electromagnetic particles with an energy proportional to their frequency. When high-energy photons interact with biological matter, they have more potential to transfer their energy and induce cellular damage. Thus, this observation highlights the crucial importance of taking into account the physical properties of photons when planning radiotherapy treatments, in order to maximize effectiveness while minimizing adverse effects on the surrounding healthy tissues.

For electrons, at energies of 2 MeV and 6 MeV, their energy is insufficient to penetrate deep into biological tissues. Therefore, the dose deposited in the target organs, such as the right kidney (tumor organ) as well as the left kidney and bladder (organs at risk), remains negligible at these energies. However, at 10 MeV, there is an increase in the dose deposited in the right kidney, although this dose remains very low, which translates into the absence of a dose deposited in the organs at risk.

For protons, at an energy of 70 MeV, their energy is insufficient to penetrate deep into the tissues of the right kidney, and therefore, no dose is deposited there. However, at 110 MeV, the energy of the protons is optimal to reach the center of the right kidney and deposit the maximum dose at that specific location. Above 110 MeV, the protons extend beyond the center of the right kidney, reducing the dose deposited in this region.

Conclusion

: Our first preliminary study showed that Kidney irradiation underscores the ballistic benefits of a proton beam. In other words, the rigorous dose deposition in treatment by these heavy and charged particles is due not only to the correlation between depth and incident energy, but above all to the abrupt drop in the dose deposition at the end of the journey. The damage that can be produced by irradiation of cells, and in particular on DNA, can also lead to biological disorders in patients with kidney cancer.

Second part, it is clearly shown that on a small sample of dialysis patients with chronic kidney issuance, biology playing an important role in the diagnosis and therapeutic follow-up of these disorders and we will recall the main recommendations issued by the international foundation "Kidney disease improving global outcome (KDIGO)" on the biological parameters to be measured and respected.

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