Artigo Original

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Numerical dosimetry of a uterus with copper IUD undergoing ^{60}Co radiotherapy treatment

Dosimetria numérica de um útero com DIU em tratamento radioterápico com ^{60}Co

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Abstract

Intrauterine devices (IUDs) are one of the most common and effective methods of contraception worldwide. Occasionally, women during reproductive age undergo radiotherapy with the implanted device, due to the non-possibility of removal caused by invasive cervical cancer. In those cases, the IUD may interact with the radiation beam leading to changes in the dose delivery for the treatment. Therefore, it is important to understand the implications of the presence of IUD implant during radiotherapy. Given that, we focused on the evaluation of the energy deposited in the uterus in treatment situations with a *^{60}Co* radiotherapy source through computational simulations, calculated by Monte Carlo N-Particle 6.2 (MCNP6.2) software. The software ParaView 5.10.1 was used to visualize the energy deposition on simulated structures. The results show that the presence of the IUD interferes with the dose distribution, and a small change was observed in the energy deposited in the tissues. Nevertheless, there was radiation scattering and alteration in the values of the energy deposited in the region where the IUD was inserted. These changes are mainly caused by the Compton and Photoelectric effects that are enhanced by the higher density of copper parts of the IUD. Therefore, the MC simulation proved to be a valuable tool to better understand the implications of IUD on radiation interactions, however further studies are needed on the dose alterations in different parts of the uterus.

Keywords: intrauterine device (IUD), cervical cancer, MCNP, *^{60}Co*.

Resumo

Dispositivos intrauterinos (DIUs) são um dos métodos contraceptivos mais comuns do mundo. Eventualmente, mulheres em idade reprodutiva submetem-se a radioterapia com o DIU implantando devido a impossibilidade de remoção causada por um câncer cervical invasivo. Assim, é importante entender as consequências da presença de um DIU implantado durante o tratamento radioterápico. Portanto, esse trabalho foca na avaliação da energia depositada no útero para tratamentos com fonte de ^{60}Co através de simulação computacional, utilizando o software Monte Carlo N-Particle 6.2 (MCNP6.2). O software ParaView 5.10.1 foi utilizado para visualizar a energia depositada nas estruturas simuladas. Os resultados obtidos mostram que quando o DIU está presente, é observada uma pequena alteração na energia depositada nos tecidos. Entretanto, há um espalhamento de radiação e alteração nos valores da energia depositada na região onde o DIU está implantado. Essas alterações são causadas principalmente pelos efeitos Compton e Fotoelétrico que são amplificados pela alta densidade das partes de cobre do DIU. Portanto, a simulação de Monte Carlo demonstrou se ser uma ferramenta valiosa para uma melhor compreensão das implicações das interações da radiação e o DIU, contudo são necessários mais estudos sobre as alterações de dose em diferentes partes do útero.

Palavras-chave: *dispositivo intrauterino (DIU), câncer cervical, MCNP, ^{60}Co.*

1. Introduction

Cervical cancer (CCU) is a slowly evolving disease that affects many women and is among the leading causes of death in emerging countries. The persistent infection by the Human Papillomavirus (HPV) is the main risk factor for the development of the CCU precursor lesions, along with factors such as age, number of sexual partners, immunodeficiency and smoking (1,2).

The types of treatment vary according to the stage of the disease and can also be combined with each other to improve patient prognosis (3). Total or partial removal of the affected organ is usually performed, in the early stages of the disease, through surgery, and, in more advanced stages, radiotherapy is used alone, or in conjunction with chemotherapy (4).

In radiotherapy, megavoltage photon beams are used to destroy neoplastic cells, preserving healthy tissues as much as possible. For cervical cancer, teletherapy is initially performed, using telecobalt units or linear accelerators, in which the source is placed at a certain distance from the patient, and, later, intracavitary brachytherapy, in which the radioactive source is inserted near or into the tumor.

Telecobalt therapy is a technique in which gamma rays emitted by the ^{60}Co isotope, present in the equipment, are applied to control the tumor cells present in the irradiated volume. In this technique, the source is placed 60 to 100 cm from the patient, generating a beam with an average energy of 1.25 MeV. This technique emerged in the early 1940s (5) and, due to its simplicity of operation and low maintenance cost (6), even with the emergence of other technologies, it is still used, with about 1766 active units worldwide (7).

In some specific cases, women undergoing radiotherapy treatment who had IUD previously implanted as a contraceptive method, before developing cervical cancer, are unable to remove this artifact due to the growth of the cervix. The IUD is a device made of polyethylene, placed in the uterine cavity, with the aim of preventing pregnancy. There are two types, which differ by their mechanisms of action and their composition, hormonal IUDs, composed of levonorgestrel, and non-hormonal IUDs, composed of copper (8,9). The latter is the object of analysis in this work.

Our analysis is based on computational dosimetry since it enables accurate radiological protection studies without the need to recruit study volunteers (10). The computer simulation for dose calculation in the human body uses virtual anthropomorphic phantoms that represent the human body in an ionizing radiation exposure scenario. Radiation transport software, such as the Monte Carlo N-Particle, MCNP 6.2, allows the estimate of the dose received by tissues or organs in exposure situation such as radiotherapy and diagnostic procedures (11).

The objective of this work was to analyze the impact caused by using the copper IUD in women with CCU who are undergoing radiotherapy treatment with a ^{60}Co source. The is study was performed based on the Monte Carlo simulation technique, using the MCNP 6.2 software, to evaluate the absorption and scattering levels of the radiation dose used in the treatment, considering scenarios with and without the use of copper IUDs.

2. Methodology

The current generation of computational phantoms, called the third generation, is developed from BREP (boundary representation), where a 3D model is defined from the limits of its volume. These BREP phantoms are composed of NURBS (Non-Uniform Rational B-Splines) and Polygonal Mesh (PM). NURBS are mathematical models used to create surfaces and curves in graphic development software such as Blender, Autocad, Freecad etc. PMs are a set of faces formed through vertices that define a three-dimensional object. The greatest advantages of BREP phantoms are their flexibility and ability to model their structures in different sizes and postures (12).

2.1. Simulation environment

The MCNP 6.2 software was used to perform the computational dosimetric analysis, since the research group has familiarity in its use and has a license to use it. MCNP 6.2. This is a radiation transport software that uses the Monte Carlo Method, developed to track different types of particles in wide energy range. The software was developed, and it is maintained by the Los Alamos National Laboratory (LANL), in its 6.2 version, among the new features, it has improved tracking of particles in mesh-like structures (11).

MCNP 6.2 does not allow phantoms elaborated with PM to be implemented directly in the simulation code, requiring the conversion of the object elaborated in PM to TM (tetrahedral mesh). To perform this task, the POLY2TET software, developed by Haegin Han, was used (13). This software converts PM phantoms from OBJ files into TM phantoms, ELE and NODE files, keeping the same contours as the polygonal surfaces. NURBS phantoms can also be used, after being converted to PM phantoms, through 3D modeling software such as Blender. In addition to conversion, POY2TET offers the option of creating input files for simulation in MCNP, PHITS and Geant4. When choosing the option to convert to MCNP, an Abaqus/CAE file is created, with an INP extension, from the ELE and NODE files.

2.2. Modeling and materials

For the simulation, a phantom that represents most of the female reproductive system was used. This object has already been used in the elaboration of other phantoms, such as the FASH3 (female adult meSH), developed by the Dosimetry and Nuclear Instrumentation Group of the Department of Nuclear Energy of the Federal University of Pernambuco (DEN/UFPE) (14). Figure 1(a) shows the reproductive system phantom, namely Y6003_ovaries, which was created and distributed by the National Taiwan University - NTU (15).

The Y6003_ovaries phantom was adjusted using the free software Blender 3.1.2 and Freecad 0.19 and the dimensions were altered to fit the size of the uterus of a nulliparous woman of reproductive age (16). For radiation transport calculations, each tissue or organ must have a defined material composition. The values defined for the uterus are in accordance with the ICRP 110 for a virtual anthropomorphic simulator of an adult female (17).

To represent the copper IUD, Figure 1 (b), a geometric mesh structure was created in Blender based on the IUD TCu380A. This structure has the shape of a “T”, made of polyethylene (PE). The horizontal arm contains two 35 mm² copper collars. A copper wire with a surface area of 310 mm² is wound tightly around the vertical stem, resulting in a total surface area of 380 mm², as indicated in the device name (18).

The copper wire was initially modeled; however, it made the simulation geometry very complex as it contains a large amount of polygonal meshes to accurately describe its structure, it contained more meshes than the uterus itself, thus requiring a great computational effort. Therefore, for this work, a simplification was made removing the copper wire and defining the vertical stem material as copper instead of polyethylene, as shown in Figure 1(c). Figure 2(a) shows the IUD positioned in the uterus.

Finally, to represent the humanoid, an object was created to represent a young woman with universal average physical characteristics, as can be seen in Figure 2(b). For this purpose, the free software MPFB 2.0-alpha2 was used, since it is a generator of mesh humanoids that works as an extension of Blender. The humanoid was named Linda 1.0, in reference to the research group that the authors of this work are part of, the LInDa – *Laboratório de Instrumentação e Dosimetria* (Instrumentation and Dosimetry Laboratory) of the Federal University of Uberlândia. The humanoid material defined was water.

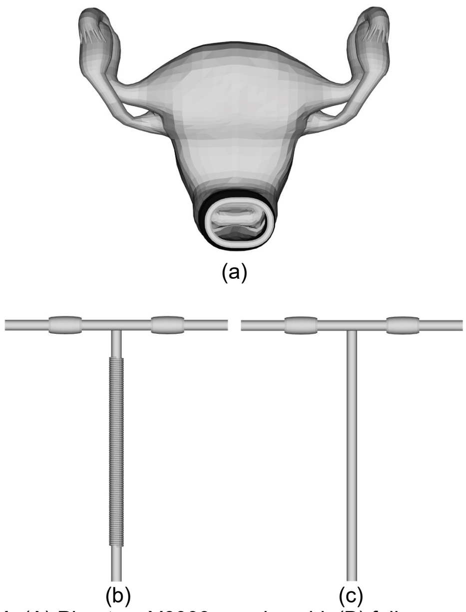


Figure 1. (A) Phantom Y6003_ovaries.obj, (B) full representation of the copper IUD, (C) simplified representation of the copper IUD.

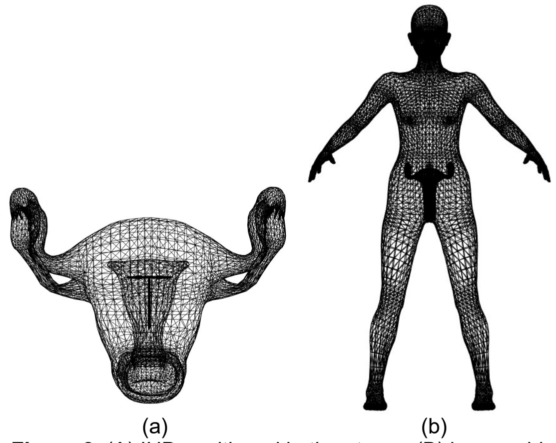


Figure 2. (A) IUD positioned in the uterus, (B) humanoid representing a young woman named Linda 1.0.

2.3. Source specification and treatment planning

The characteristics of the ^{60}Co source, its decay probabilities and energy were based on the paper by Tedgren et al. (20). A monodirectional cylindrical source with a radius of 2.5 cm was modeled and placed 100 cm from the uterus (5). The beam direction is anterior-posterior.

For this study it was determined that the generated particle would be the photon and the traced particles, photons and electrons. Two scenarios were simulated in which 1E9 particles were transported, one with and one without the IUD.

2.4. Tally specification

Specifying the tally in MCNP 6.2 means determining which information of interest will be recorded in the Monte Carlo simulation output files. MCNP 6.2 provides different default tally options (11). The chosen one for this simulation was the mnemonic *+F6* (collision heating), which contains the energy deposited from all the particles in the problem, for each specified surface (e.g. uterus). The measurement unit of the obtained data using *+F6* was MeV/g/source-particle.

2.5. Visualization of results

The software ParaView 5.10.1 was used to plotted the energy bins from elemental edit output file (.eeout). To obtain the data for visualization in ParaView, a Python script written by Joel A. Kulesza and Tucker C. McClanahan from the Monte Carlo Methods, Codes, and Applications Group, from Los Alamos National Laboratory was used (21). It converts the EEOUT output file from MCNP simulation and results into a VTK (.vtu) file.

3. Results

The estimated deposited energy and the relative error of each value for each structure of the geometry are presented in Table 1. The uncertainty values are acceptable, since, according to the MCNP 6.2 manual, values lower than 5% determine reliable results for all types of investigations (11). This information is important, as it validates the modelled geometry and conversion processes, previously detailed.

By comparing the results of Table 1, the Linda 1.0 phantom presented a lower value of deposited energy when the IUD was present. For the uterus without the IUD, the energy deposited was 0.007% higher, with a relative error of 0.01%. The difference is not significant since it was lower that the uncertainty.

The low dose differences found in this work should not be overlooked since we only evaluated the IUD effects on the dose. The presence of metallic IUD components during a complete radiation treatment can adversely affect the quality of images obtained from Computer Tomography (CT) or Magnetic Resonance Imaging (MRI). Consequently, these image quality issues can have repercussions on delineation, dosimetry, and the accurate delivery of the prescribed radiation dose (22). Physical phantom and Monte Carlo studies have also reported small dose distribution differences when the photon beam was aimed to a tumor near metallic implants. However, a cadaver study reported a 21,9% reduction in measured mean dose compared to the calculated treatment dose (23). This result indicates the need for more studies on the matter, including the development of more realistic simulations capable of represent the inhomogeneity of biological tissues characteristics.

Table 1. Deposited energy

Configuration	Energy deposited (MeV/g/particle-history)	Relative uncertainty (%)
Uterus with IUD	3.73E-4	0.01
Uterus without IUD	3.73E-4	0.01
Linda 1.0 with IUD	8.77E-6	<0.01
Linda 1.0 without IUD	8.77E-6	<0.01

Source: The autor (2023).

In Figure 3, the uterus is presented laterally. Figures in this paper allows visualizing the energy deposited in the polygonal meshes that represent the structures and organs of the study, through a gradient between dark blue and dark red, where 0 MeV is dark blue and 3.7E-4 MeV is presented as dark red.

In Figure 4, in ParaView's "wireframe" visualization mode, the placement of the IUD in the uterus and the energy deposited in the border regions (edges) of each polygonal mesh are observed. In Figure 5(a), using the "volume" visualization mode of ParaView, for the uterus scenario without the IUD, we may observe the areas where there is higher energy deposition and the way in which the photon and electron beam interacts with the matter.

In Figure 5(b), using ParaView's "volume" visualization mode, for the scenario of the uterus with the IUD, it is noticed that the presence of the IUD causes an interference in the way energy is deposited in the uterus. These differences arise from the radiation interactions with the IUD materials, primarily the copper parts since they have higher density than the biological tissue. The higher density favors both Photoelectric and Compton effects, the latter being the predominant interaction at radiotherapy energies. To the best of our knowledge, there is no study on the effects of metallic IUD on CCU radiotherapy treatment. Therefore, it is only possible to compare the results obtained in this article with the literature on the effect of metallic implants which also reported differences on dose distribution (23–25).

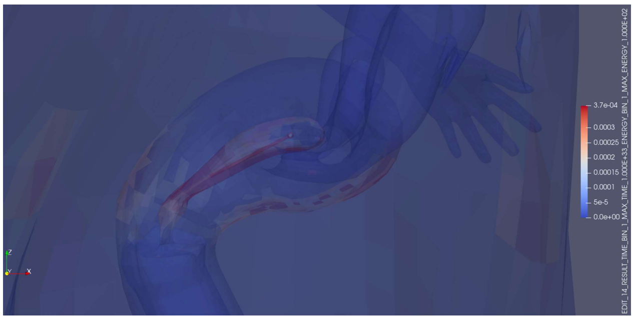


Figure 3. Lateral section of the uterus, positioned in space according to the orientation axes in the lower left corner of the image.

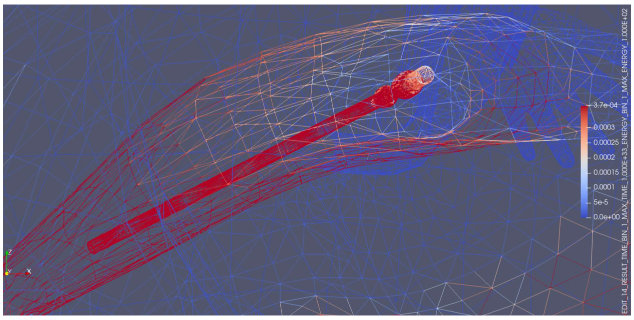
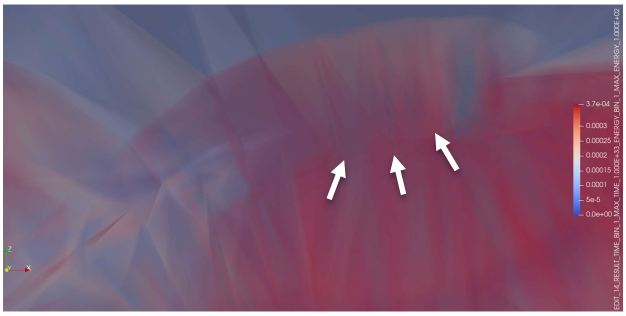
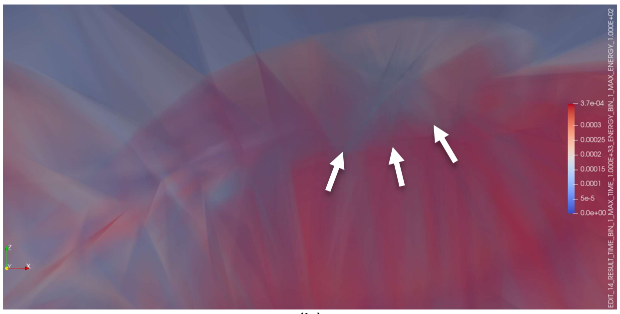


Figure 4. View of the IUD and uterus in ParaView's wireframe mode.



(a)



(b)

Figure 5. (A) Distribution of energy in the uterus with the copper IUD. (B) Distribution of energy in the uterus without the copper IUD. The arrows point to the region where the change in dose is observed.

5. Conclusion

We conclude that the presence of the IUD does not significantly modify the energy deposited in the uterus during a CCU radiotherapy treatment using a ^{60}Co source, however, it causes an interference in the way the energy is deposited in the tissues of the uterus. Thus, we suggest in further studies based on case studies to verify if these anomalies can impair the process to reach the therapeutic dose in radiotherapy treatments, where irradiation occurs and, due to neoplasia, it is impossible to remove the IUD before treatment.

The use of 3D modeling software proved to be a viable option for the development of future scenarios for dosimetric analysis through computer simulation and, among its greatest advantages, are the agility and flexibility of work. By improving the modeling objects technique in Blender and using more advanced ParaView functions, more complex and yet, unexplored simulation scenarios may be investigated.

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