T1, T2 parameters evaluation of clinical gel/$CuSO_4$ by MRI and NMR spectrometry after low dose gamma irradiation

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Abstract

Magnetic Resonance Imaging (MRI) has been shown to be an emerging technique for planning and monitoring radiotherapy treatments, adding data to images obtained by Computed Tomography (CT). On the other hand, its use could be strategic to control the absorbed dose due to the treatment, adding dosimetric information. This work presents a study of the MRI alterations of clinical gel/$CuSO_4$ compounds after irradiation with gamma doses between 1-4 Gy. The samples were irradiated in Multipurpose Panoramic Irradiator equipped with Cobalt-60 source. Materials were evaluated by MRI with General Electric Company (GE) equipment of 1.5 Tesla. Furthermore, relaxometry was used to study relaxation variables in MR (T1 and T2) by Nuclear Magnetic Resonance Spectrometry (NMR) with Bruker Advance DPX 200 equipment of 4.7 Tesla. We discuss the MRI results in terms of signal intensity, evaluated with ImageJ® software, in comparison with relaxometry data, obtained by NMR. T2 decay curves constructed through the relationship between signal intensity (obtained with ImageJ®) and Time to Echo (TE) variation, was used to compare with the T2 decay curves obtained by NMR. The T1 relaxometry data obtained by NMR was used to establish a relationship with the radiation dose, as a proposal for dosimetric control. The curve showed a first-order exponential relationship between the absorbed dose and the signal intensity. The results encourage further studies of the material and its potential for visual and quantitative dose control in cobalt therapy.

Keywords: Cobalt therapy; Magnetic Resonance Imaging; Nuclear Magnetic Resonance Spectrometry; Dosimetry.

1.- INTRODUCTION

Technological improvements have led to widespread capabilities to deliver highly conformal intensity modulated radiation therapy (IMRT), evolving, including, for image guided radiation therapy (IGRT). The application of magnetic resonance image (MRI)–guided brachytherapy, for example, has demonstrated significant growth, besides is now standard in cervical cancer due to more accurate tumour and organ at risk delineation leading to improved tumour control and decreased morbidity [Tanderup *et al.*, 2014; Chin *et al.*, 2020]. According to Kishan *et al.* (2015) these advances allow pretreatment or even intratreatment imaging to be used to verify that radiation is being delivered as intended [Kishan *et al.*, 2015]. More specifically, the use of MRI-associated radiotherapy confers advantages over the use of computed tomography (CT): it does not use additional ionizing radiation and is the imaging modality that provides better contrast to some regions of the body. Today, Magnetic resonance-guided radiation therapy (MRgRT) is a reality. However, studies of dosimetric systems aimed at controlling these treatments are still necessary. This is because there are current limitations related to the presence of the magnetic field and its influence on dosimetry. The dosimetric control of radiotherapy treatments is important to ensure their effectiveness with safety. Although MRI offers advantages in its associated use for planning and monitoring radiotherapy treatment, MRI-based dosimetry is still considered inaccurate, bringing demand for research in the area [Chin *et al.* 2020]. According to Chin *et al.* (2020), the presence of a magnetic field can affect dosimetry through the effect of the Lorentz force on secondary electrons, which at density changes (e.g., from tissue to air) makes the electrons return onto the surface of the tissue. The electron return effect can also cause challenges for measurements of dose on MRgRT systems, and cause hotspots when unplanned gas pockets occur during treatment [Chin *et al.*, 2020]. It is in this scenario that the present study is situated, since it proposes the use of a compound with magnetic properties for dosimetric studies associated with MRI-guided radiotherapy treatments. In this sense, in a preliminary way, we propose the study of the clinical gel/$CuSO_4$ material in relation to the variation of the T1, T2

parameters, when exposed to radiation doses consistent with fractioned doses in radiotherapy treatments.

It aims to investigate the potential use of the material for dosimetric comparison between radiotherapy planning and experimental measurements. It starts from the hypothesis that it is a compound sensitive to irradiation at low doses, leading to the possibility of associating the variation of the T1 parameter with the dose absorbed to the material. It provides for the use of the T2 parameter as an indication of confidence in relating signal intensity data obtained from MRI with Nuclear Magnetic Resonance (NMR) spectroscopy data, adding this technique to dosimetric control.

2.- MATERIALS AND METHODS

$CuSO_4.5H_2O$-added clinical gel samples were obtained by hand mixing $CuSO_4.5H_2O$ (100 mg) in 100 ml RMC® Colorless Clinical Gel from Unigel [Bolfe et al., 2009]. The samples produced were separated into vials to be irradiated. Pure gel sample were also separated for MRI and NMR as well as non-irradiated compound sample. Samples were irradiated in Multipurpose Panoramic Irradiator of *Centro de Desenvolvimento da Tecnologia Nuclear (CDTN)* using a Co-60 source at constant dose rate, for doses range between 1-4 Gy.

After irradiation, the samples were placed in a polypropylene box to obtain the MR images. Scanning was performed by 1.5 T GE equipment, in one slice which was positioned in the middle of the tube with slice thickness of 5 mm. T1-weighted images (T1WI) were obtained using spin-echo sequence, parameter of matrix size = 256 × 256, with Time to Echo (TE) = 10 ms and Repetition Time (TR) = [50, 100, 150. 300, 400, 500, 750, 1000, 1500 ms]. T2-weighted imaging (T2WI) with multiple spin-echo sequence was used to obtain images with parameter of matrix size = 256 × 256. The whole scanning was conducted with repetition time (TR) of 5000 ms. The TE variation was used to obtain T2 images TE = [10, 100, 200, 300, 400, 500 ms]. Images were then processed to obtain signal

intensities by regions of interest (ROI) of rectangular in shape using a free image processing software, ImageJ® (NIH, US). T2 curves were acquired by plotting signal intensities exponentially against Time to Echo (TE).

Nuclear Magnetic Resonance Spectrometry (NMR) was obtained on a 4.7 T Bruker DPX 200 NMR scanner. The samples were prepared using D_2O solvent.

3.- RESULTS

Figure 1 shows the MR images obtained at T1-weighted and T2-weighted of pure gel sample and clinical gel/$CuSO_4$ composites irradiated with gamma doses of 1 to 4 Gy. The images were used to obtain the signal intensity value, using the ImageJ® processing software.

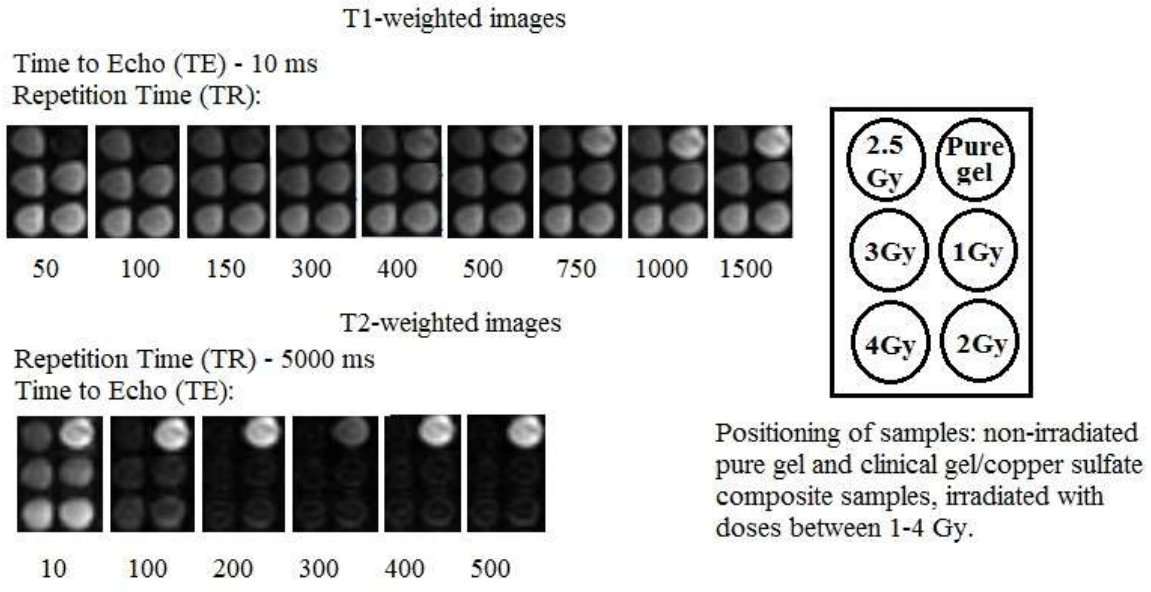


Figure 1.- Images obtained of T1-weighted and T2-weighted scans. The schematic drawing demonstrates the positioning of the samples in the images.

In Figure 2, it is possible to observe that there was no variation in signal intensity with increasing TE of the pure gel sample, in T2-weighted images. This demonstrates the role of $CuSO_4$ in the final magnetic properties of the clinical gel/$CuSO_4$ composite, inducing magnetic susceptibility effects.

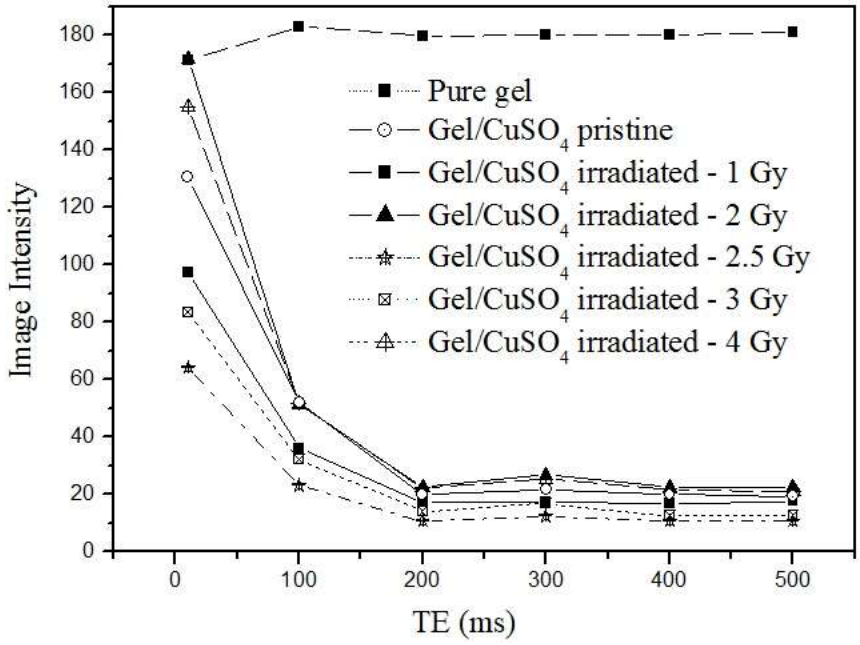
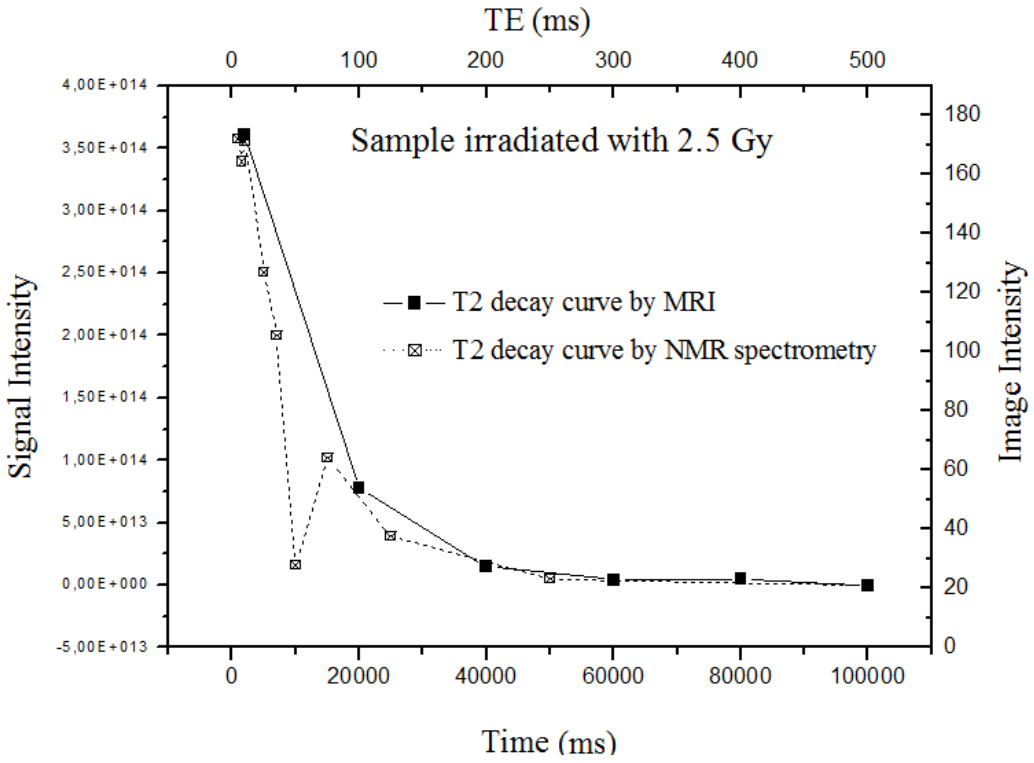


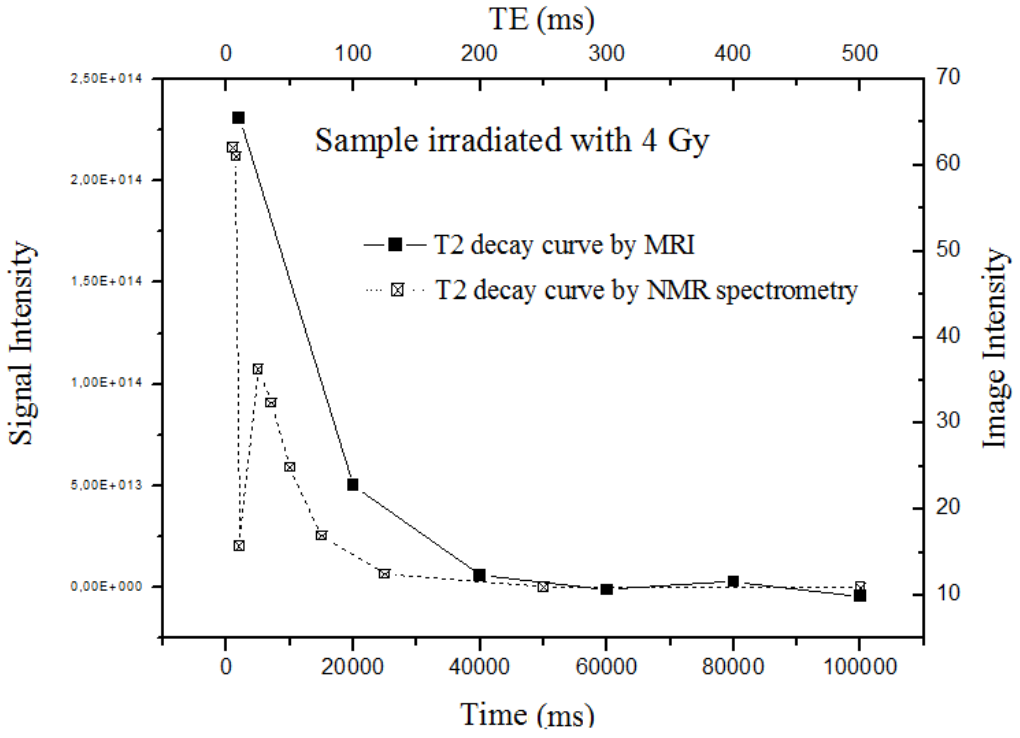
Figure 2.- Fitting of Time to Echo (TE) vs intensity to obtain T2-values at TR = 5000 ms.

For T2-weighted images the signal intensity decreases as TE increases because of T2 decay, magnetic field inhomogeneities, magnetic susceptibility variation and chemical shift of the samples. The decreasing signal intensity along with increasing TE was plotted to obtain T2-values and described in Figure 2, was given at TR = 5000 ms. The signal intensity was perfectly fit to TE and indicated the suitable fitting model for predicted in the literature [Dwihapsari *et al.*, 2020]. Considering the adjustment as adequate, a comparison was made with the data obtained through the NMR technique, for a comparison of the behavior of the T2 decay of the samples irradiated with doses of 2.5 and 4 Gy.

The good agreement of the results obtained through the MRI and NMR techniques for T2 decay data of the samples encouraged the study of T1 relaxometry, obtained directly by NMR, with dosimetric purposes (Figure 4). The choice of T1 relaxation data to evaluate the dosimetric potentialities of the composite was due to the fact that T2-weighted imaging are obtained using spin-echo sequence by weighting transverse magnetization which causes decay due to spin-spin relaxation and magnetic field inhomogeneity. The use of T1-weighted images is considered appropriate as they are not subject to the lack of homogeneity of the magnetic field, which interferes with the data obtained in the T2 decay.



(a)



(b)

Figure 3.- T2 decay curves obtained by MRI and NMR of clinical gel/$CuSO_4$ samples irradiated with gamma doses of 2.5 Gy (a) and 4 Gy (b).

In Figure 3, we observed that the MRI data used to obtain T2 decay curves from the irradiated composite samples adjusted properly, comparing with the curve obtained directly by NMR-spectrometry. It demonstrates that the two techniques can be used together, although one evidences changes in the image and the other due to quantitative data. In fact, the NMR-spectrometry is already used for dosimetric purposes, due to the reliability of the data obtained through the technique [Araujo *et al.,* 2021]. On the other hand, MRI images enable visual monitoring of the irradiation process, which is strategic for routine medical follow-up.

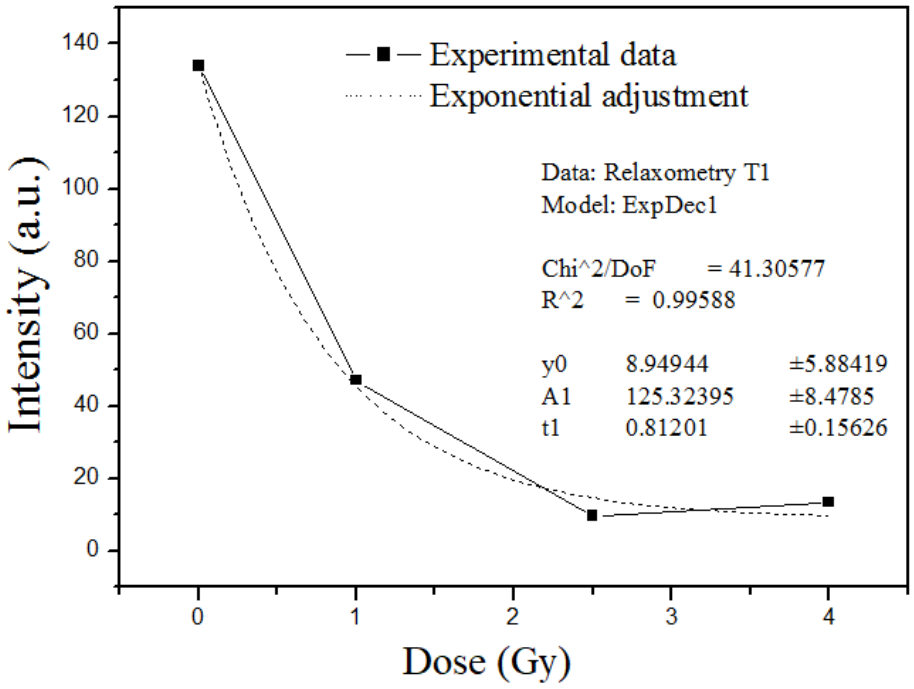


Figure 4.- Correlation analysis for T1 values obtained by NMR-spectrometry and absorbed dose.

It can be seen in Figure 4 that it was possible to obtain, through the experimental data, a first-order exponential fit, relating the t1 values obtained by NMR with the absorbed dose. The quantitative data obtained by NRM made it possible to directly evaluate the effect of radiation on the irradiated composites, with regard to the variation in parameters T1 and T2. n this sense, the technique can be used in association with perceptible changes in the images obtained by MRI.

4.- DISCUSSION

The constant technological changes in the area of radiation dosimetry come from specific demands that arise with new modalities of use of radiation for medical treatments. Dosimetric control is essential for safe exposure to well-defined regions in radiotherapy planning. Magnetic resonance imaging (MRI) has been used to aid in planning, as has computed tomography (CT). New advances have brought the possibility of monitoring the

treatment with MRI, following the effects of the irradiation process. However, the MRI magnetic field interferes in dosimetric systems. According to Rankine *et al.* (2017), a major consideration for MRgRT treatment planning systems (TPSs) is the effect of the magnetic field (B_0) on high-velocity charged particles released via photon interactions. The researchers point out that a charged particle moving in the presence of a magnetic field will experience a Lorentz force perpendicular to its velocity, altering its path of travel and subsequent dose deposition. Simulations and measurements have shown that dose kernels from a photon beam will be asymmetrically skewed under the influence of a strong B_0 [Rankine *et al,* 2017].

Several systems have been proposed to overcome dosimetric challenges, however, they focus on the interaction processes of radiation with dosimetric material. So, for example, Stark *et al.* (2020) performed different end-to-end tests monitored the accuracy of MR-Linac during the first year of clinical operation. They report on the stability of these tests covering a static, adaptive and gating workflow. For this used a microDiamond detector (PTW Freiburg, Freiburg, Germany) inserted into a target rod moving longitudinally with an amplitude of 7.5 mm within a body-like support structure [Stark *et al.,* 2020]. In another research, Shrestha *et al.* (2020) conducted research with the objective of to demonstrate the potential application of Al_2O_3:C and Al_2O_3:C, Mg optically stimulated luminescence (OSL) films for 2D dosimetry in MRgRT [Shrestha *et al.,* 2020]. For this work, it is proposed a material that can both evidence the processes irradiation by direct physical parameters, as well as by changes in the image obtained by MRI. In this sense, sought to associate the techniques for quantitative and visual control, bringing a new perspective to dose control in MRgRT.

5.- CONCLUSIONS

Clinical gel/$CuSO_4$ composed was tested for dosimetric purposes, by studying the T1, T2 parameters variation. We sought to highlight the potential of the joint use of an assessment through MRI and NMR-spectrometry. Thus, it proposes the use of the same set of

parameters with two different analysis techniques It was found that the MRI obtained from samples irradiated with doses between 1 and 4 Gy demonstrate variation in the intensity of the image in relation to the non-irradiated sample. The T2 decay curve obtained by plotting image intensity data by increasing TE values showed similar behavior to the curves obtained by NMR. The T1 relaxometry data obtained by NMR were plotted considering the absorbed dose and showed a first-order exponential correlation. The results are promising and demonstrate the material's potential for dosimetric use, in the context of MRgRT.

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