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Dose enhancement caused by gold foils on polymer gels

L.C. Afonso; M. Greiter; F. Schoefer; C. Hoeschen

Helmholtz Center Munich, Ingolstaedter Landstrasse 1, 85764 Neuherberg, Germany

luciana.afonso@helmholtz-muenchen.de

Abstract. The presence of high-Z materials adjacent to soft tissues, when submitted to irradiation, locally enhances the absorbed dose in these tissues. This effect is due to the outscattering of photoelectrons from the high-Z materials. The aim of the present work was to measure the absorbed dose enhancement caused by gold foils on polymeric gel.

1. Introduction

Previous studies showed that the presence of high-Z materials adjacent to soft tissues, when submitted to irradiation, enhances the absorbed dose in these soft tissues. Such effects happen due to the outscattering of photoelectrons from the high-Z materials. [1, 2, 3]

The concern about the effect of dose enhancement arose after discovering that oral cavity radiation therapy treatments on patients that had golden tooth replacements resulted in an increased damage of the soft tissues surrounding these gold replacements. It was found that the absorbed dose could reach an enhancement of two orders of magnitude in the microscopic vicinity of gold replacements, when exposing the patient to diagnostic X-ray examinations. [1]

In experiments with human lymphocytes covered with a thin gold film and then irradiated with diagnostic X-ray beams, it was found that the dose absorbed by the cells was increased by a factor of 45.4. The number of chromosomic aberrations was also in accordance to this dose enhancement. [2]

Thereby, the aim of the present work was to measure the absorbed dose enhancement caused by the presence of gold foils on the surface of polymeric gel samples, whose main characteristic is the soft tissue equivalence. The polymer gel dosimetry associated to the Nuclear Magnetic Resonance technique allows the absorbed dose to be measured with high three-dimensional resolution, providing the spatial distribution of the dose enhancement caused by the photoelectrons outscattered from the gold foil.

2. Dosimetric Method

In order to resolve local dose distributions in soft tissue equivalent material close to high-Z materials polymer gel dosimetry was used.

Polymeric systems were first studied in relation to their dosimetric capacity in the fifties, by evaluating the radiation effects in poly-methyl-methacrylate [4]; and studying radioinduced polymerization in liquids [5]. Later works combined these properties as the first polymer gel developed by Maryanski et al [6, 7], which used a formulation that was composed by acrylamide, bis-acrylamide and nitrous oxide diluted in an agarose aqueous matrix.

Further gel formulations were developed by changing the gel matrix (agarose to gelatin), the monomer (acrylamide to methacrylic acid, for example), etc. However, the working principle of any polymer gel dosimetry is based on the radiation-induced polymerization of the monomers present in the gel. When the gel is irradiated, water radiolysis is induced. The polymerization process is mainly initiated by free radical reactions. The polymerization degree depends on the number of free radicals created by the incident radiation, which depends on the absorbed dose; therefore, originating spatial dose resolution. [8, 9]

The polymer gel used for this work is known as MAGIC (Methacrylic Ascorbic in Gelatin Initiated by Copper), foremost developed by Fong et al [10]. Its formulation is composed by methacrylic acid, ascorbic acid, gelatin and copper sulfate. As the gel polymerization process is initiated by free radical reactions, and molecular oxygen is an efficient “scavenger” of free radicals, its presence inhibits gel polymerization. The ascorbic acid, in a process initiated by the copper sulfate, is responsible for capturing oxygen in the gel solution.

3. Methodology

3.1. Polymer Gel Preparation

The polymer gel samples used in this study were produced using deionized water, gelatin (swine skin, 300 bloom, Sigma Aldrich), methacrylic acid (99%, Sigma Aldrich), copper (II) sulfate penta-hydrate, and ascorbic acid (extra pure, Merck).

At room temperature, 140 g of gelatin were added to 700 ml of water. After the water has been absorbed by the gelatin, the mixture was heated to 55 °C in a water bath and was let to liquefy for approximately 1 hour. The ascorbic acid (0.3522 g) was added; then, copper (II) sulfate (0.025 g); and finally the methacrylic acid. After each reagent has been added, the gel was mixed thoroughly. The mixture was kept in the water bath for more approximately 1 hour. Afterwards the gel was poured into 12 glasses (50 ml, 5 cm of diameter), which were previously immersed in an oxygen scavenger solution (water, ascorbic acid and copper (II) sulfate) for 6 hours. The filled glasses were covered with cling film (14 ± 2 μm) and were positioned upside down in an oxygen scavenger solution, in order to prevent oxygen penetration through the cling film into the polymer gel.

3.2. Irradiation

The polymer gel samples were irradiated 24 hours after production. A Philips Industrial X-rays (now Yxlon International) system with a MCN 323 tube was used to generate x-rays at 200 kV, 15 mA filtered with 0.96 mm Cu and 4.05 mm Al. A PTW ionization chamber (type 23361, 30 cm³ sensitive volume) coupled with a PTW Unidos electrometer was used for the dose measurement.

Gold foils (thickness about 100 nm) were placed on the cling film surface of each sample, covering half of the surface area (Figure 1). The polymer gel samples were individually positioned with the cling film surface perpendicular to the beam at the reference point at 70 cm from the x-ray focal spot (Figure 2). Irradiation doses, measured as air kerma at the reference point, were 0, 1, 2, 3, 4, and 5 Gy, attained at a constant dose rate of 4.52 mGy/s (± 1.5 % combined uncertainty; including positioning, calibration factors, instrumental stability, and corrections for air density). Two samples per dose were used.

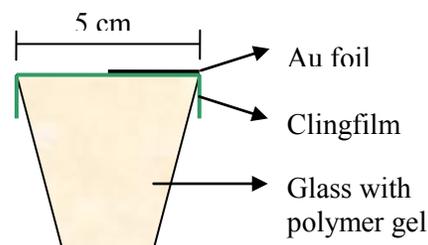


Figure 1: Schematic representation of a sample.

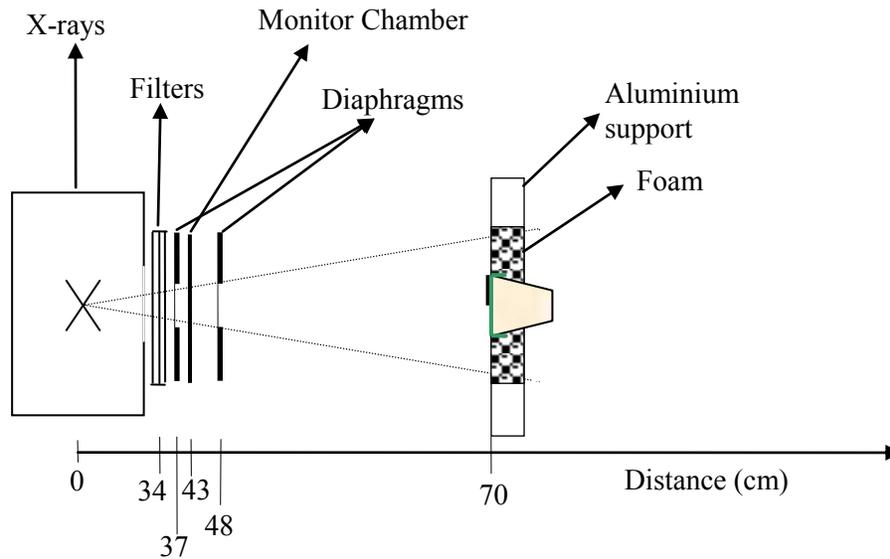


Figure 2: Irradiation set-up (not to scale).

3.3. NMR Scanning

After approximately 17 hours the samples were scanned using a Bruker BioSpin system (BioSpec 94/20 USR, 9.4 T). A Multi Slice Multi Echo sequence (MSME) was used with FOV = 6 x 6 cm², echo times of 20, 40, ..., 320 ms and a repetition time of 2500 ms. One slice with 1mm thickness was measured in the surface of each sample. The T2 values were obtained by fitting all signal echoes to a monoexponential function. Then, the transversal relaxation rates ($R2 = 1/T2$) were related to the doses. Two R2 in different regions of interest (ROI) per sample were measured; one under the area covered by the gold foil and the other out of the area covered with gold. The gold foils were removed before the scanning.

4. Results and Discussion

The relation between R2 and the dose is represented in the Figure 3. It is observed that the relaxation rates measured under the gold foils are greater than those measured in the area free of gold. One can observe that the slope from the linear regression of the measurements in the area with gold is greater than the slope obtained from the measurements in the area without gold. This indicates that the presence of gold foils on the surface of the samples caused a dose enhancement in the vicinity of these gold foils by 16%. This result can serve just as an estimate because of two important factors: the thickness of the gold foils was not known exactly; and the gold foils were very flexible and easily torn, so the difficulty of dealing with such foils caused that some small areas were not well covered.

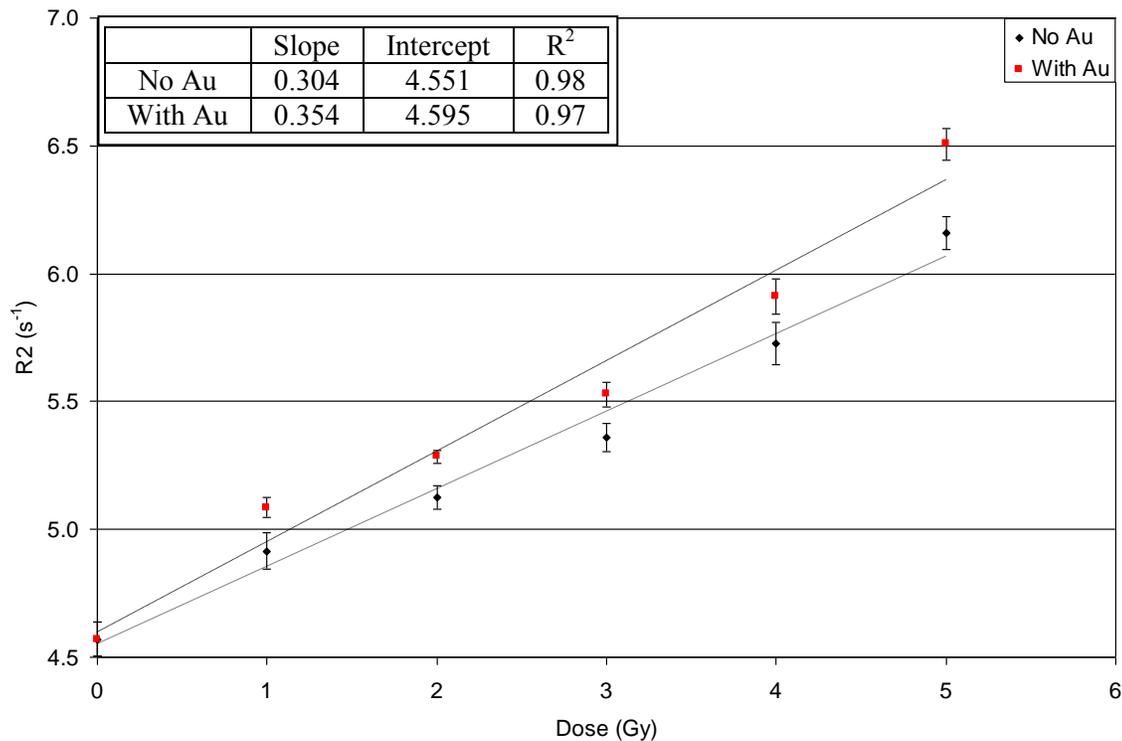


Figure 3: Relation between R2 and the dose. The red squares represent the area covered with gold foils and the black lozenges represent the area not covered with gold foils. The error bars represent the standard deviation of the R2 in the ROI.

5. Conclusion

The result of this study indicates the effect of dose enhancement in the area adjacent to the gold foils. Nevertheless, taking into account that difficulties mentioned above may play an important role, the experiment will be repeated using more resistant gold surfaces (i.e., thicker foils or plates) in order to assure this result and achieve a better quantification. The scanning will be performed with thinner slices, with a sequence of slices into the depth of the gels.

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