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INTERNATIONAL ADVANCED RESEARCHES
and
ENGINEERING JOURNAL

Journal homepage: www.dergipark.gov.tr/iarej

e-ISSN: 2618-575X

International Open Access

Volume 02
Issue 02

August, 2018

Research Article

Dosimetric Fricke Gel Systems Improved with $CaCl_2$ and Gluconic Acid

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ARTICLE INFO

Article history:
Received 28 February 2018
Revised 13 May 2018
Accepted 15 May 2018

Keywords:
Dosimetric gel
Fricke gel
$CaCl_2$
Gluconic acid

ABSTRACT

Today, cancer is an increasingly important health problem that comes immediately after heart and vascular diseases as a cause of death. In this study primary objective is to generate an alternative to dosimetry systems that are not practical and cost effective due to increasingly complex external beam radiotherapy techniques. For this purpose, $CaCl_2$ or Gluconic acid added dosimetric Fricke gel compounds were improved to mimic human tissues by means of interaction with X- rays. The MR intensity values were linearly changed depending on the concentrations of the produced gel samples and the dose amount of the applied radiation.

1. Introduction

Radiation dosimetry and calculation methods are important for the efficient delivery of radiation from devices and avoiding unnecessary doses to the target organ or tissue in cancer treatments. Although radiation is used in the treatment of cancer due to the lethal effect on the tumor cells, normal tissues may be damaged due to overdose.

Current radiotherapy planning systems that calculate the total dose to be given to the patient are based only on theoretical simulations and it cannot be confirmed experimentally whether the radiation dose to the patient is higher than the critical values of healthy organs and tissues. Determination of the three-dimensional (3D) dose distribution given to the patient by the devices working with ionizing radiation used in radiotherapy and radiology is now possible only with gel dosimeters or anthropomorphic phantoms which is the imitation of human body in terms of shape and radiation interaction [1,2].

Tissue equivalent gel-based dosimeters were used as a method to measuring dose distribution and attracted much attention today due to its advantages such as accuracy, 3-D and high resolution, less dependence on energy. There are two basic dosimetric gel groups namely Fricke gels and polymeric gels [3].

Fricke gel is prepared by taking the aqueous iron sulphate (Fricke) solution into a gel matrix. In this system, conversion of acidic, oxygen-enriched aqueous Fe^{2+} ions to Fe^{3+} is the dosimetric basis of the Fricke gel. The amounts of Fe^{3+} ions depend on the energy absorbed by the solution [4]. Modern Fricke gel technology was born with this development. Different materials such as benzoic acid [5], formic acid [6] and alcohol [7] were added to increase the sensitivity of the gel and ferric ion production in response to applied beam. Gluconic acid is an organic acid which is used in food industry and it is a natural constituent of fruits [8]. In this study, it was aimed to produce more sensitive, tissue equivalent gels for the applied radiation dose by adding non toxic, biodegradable calcium chloride($CaCl_2$) or Gluconic acid in to classical Fricke gels.

2. Material and Method

2.1 Production of Fricke Gels

Five different groups of Fricke gels were produced in this study. All of them are mainly composed of 1% gelatin and deionized water. When the acidic $FeSO_4$ solution is added to gelatin and water, this mixture is named as Fricke gel. Initially four different Fricke gels were produced, containing only 0.125 mM, 0.250 mM, 0.50 mM, 1 mM FeSO4. For the production of other dosimetric gels 0.25 - 0.5 M $CaCl_2$ or 0.5 - 1 mM glukonic acid were added in to these four different Fricke

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Table 1. Compositions and names of gels

Name of gel								
Additive	FC1	FC2	FC3	FC4	FL1	FL2	FL3	FL4
$FeSO_4$(mM)	0.125	0.25	0.5	1.0	0.125	0.25	0.5	1.0
$CaCl_2$ (M)	0.25	0.25	0.25	0.25	0.5	0.5	0.5	0.5
Name of gel								
Additive	FG1	FG2	FG3	FG4	FA1	FA2	FA3	FA4
$FeSO_4$(mM)	0.125	0.25	0.5	1.0	0.125	0.25	0.5	1.0
Glukonic acid (mM)	0.5	0.5	0.5	0.5	1.0	1.0	1.0	1.0

gels. Compositions and names of these gels are given in Table 1. Gel fabrication method previously described by Gambarini et al [9]. Deionized 400 ml water heated to 85°C, than 4 g of bovine gelatin was added and mixed at 400 rpm for 5 minutes with a magnetic stirrer under an air flow at 20Lh^{-1}. During the 20 min the solution was left to boil for saturation and then cooled down to 70 °C. The solution was then removed from the magnetic stirrer and the $FeSO_4$ solution was added to each 100 ml sample to give concentrations of 0.125 mM, 0.250 mM, 0.50 mM and 1 mM respectively. The gel solutions were manually mixed for 10-15 seconds and poured into the polyethylene spectrophotometer cuvettes. The samples were maintained at 4 °C until their analyses were done. Figure 1 shows the photographs of gel solution preparation and gel samples in cuvettes before irradiation process.

Figure 1. Gel samples in cuvettes and preparation of them.

2.2 Irridation and determination of MR intensity values of Fricke Gels

Prepared gels were irradiated with linear accelerator x-ray radiation at 6 MV with doses between 0 - 250 cGy with increments of 50 cGy. The samples were maintained at least 30 min at room temperature before the MRI evaluations. Irradiation process and the MR measurements were performed within 24 hours after gel production for increasing the accuracy and sensitivity of the analysis. Figure 2 shows the photographs of irradiation of gels and MR images after irradiation process. Irradiated gel dosimeters are scanned by a 3T MR system (Siemens Skyra, Germany) at T1 weighted sequences in 2 hours after irradiation.

Acquired images are evaluated and MR intensities with standard deviations in ROIs' (Region of Interest) are measured using a software (Siemens, Syngo Via, Germany). FT-IR analyses of Fricke gels were done before and after irradiation process by Vertex 70 FT-IR spectrophotometer in ATR mode.

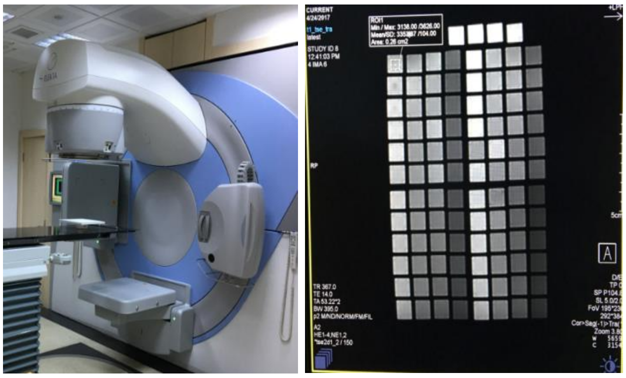
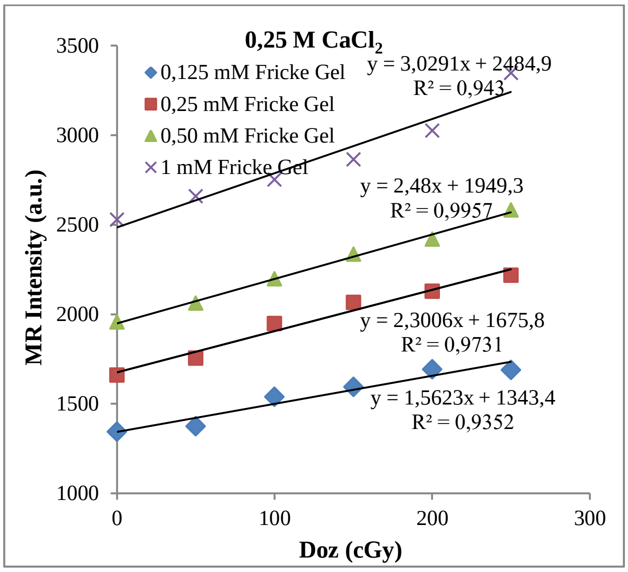


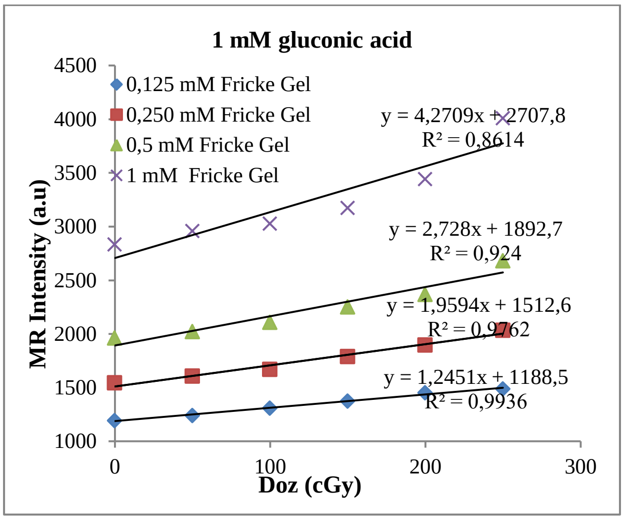
Figure 2. Irradiation process and a MR image of irradiated gels.

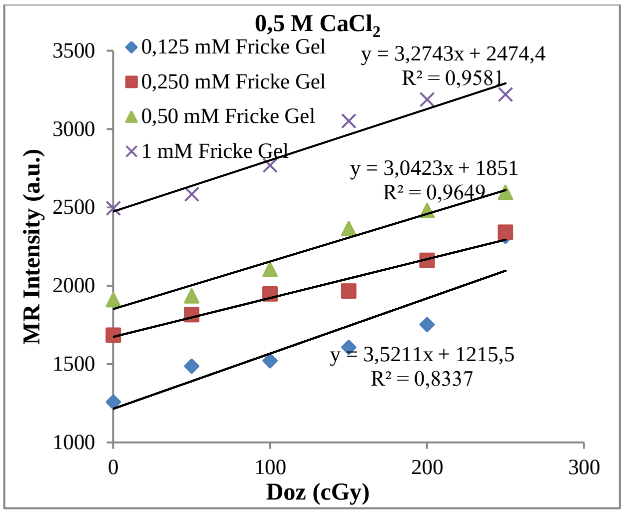
3. Results and Discussion

The MR intensity values obtained from the ROIs were plotted against the irradiation dose and the linear correlation equations were obtained with in Fig 3 Besides all slopes of fitted lines are similar, in Figure 3 it can be seen that highest consistent slope of fitted lines are obtained at FC4, FL4 and FA4 gel dosimeters. This may give the most sensitive radiation dosimeter in these study groups. It is apparent that dose sensitivity increases with increasing of concentration of $FeSO_4$. The increase in dose sensitivity allows dose distribution imaging to be more effective.

As an example the FT-IR spectrum of the FA4 gel before and after irradiation process is given in Figure 4. It is seen that the major peaks in the spectra belong to the gelatin (C-N bond at 1500 cm^{-1}, N-H bond at 3300-3400 cm^{-1}, C=O bond at 1600 cm^{-1}, etc. [10,11]), iron oxide and iron hydroxide (Fe-O at 573-579 cm^{-1}, Fe-OH at 943-993 and 3340 cm^{-1}[12]) given in the literature. It has been observed that the irradiation process does not make a significant change in the FT-IR spectrums of the gels containing gluconic acid, especially at high concentrations.







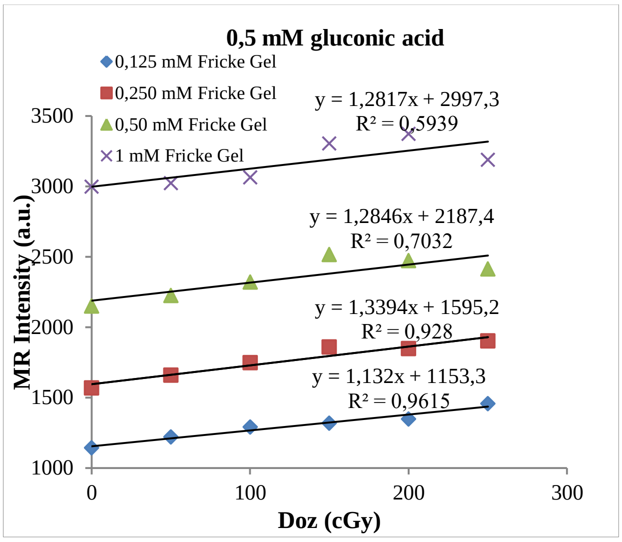


Figure 3. MR intensity values against irradiation dose

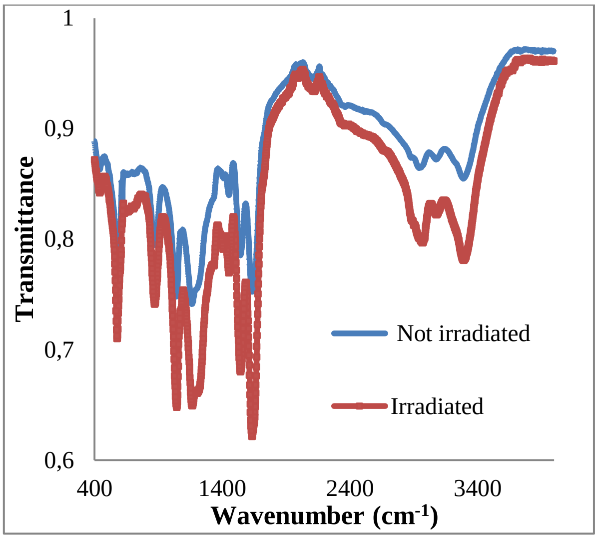


Figure 4. FT-IR spectrum of the FA4 gel before and after irradiation process.

MR images of the gels including 0.25 M $CaCl_2$ is showed in Figure 5. The image brightness increases with increasing $FeSO_4$ concentration and irradiation dose.

As can be seen from the Figure 3, Figure 4 and Figure 5, the produced gel dosimeters give different responses to the doses of the applied radiation. This demonstrates their utility as a dosimetric gel.

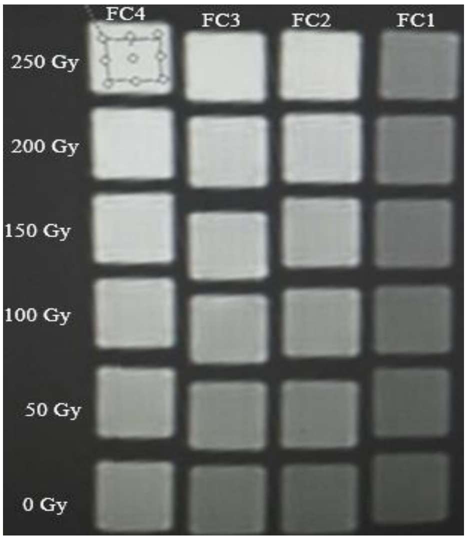


Figure 5. MR images of gels including 0.25 M $CaCl_2$ at various irradiation doses.

4. Conclusions

It is very important to calculate the doses received by cancer patients during radiotherapy treatments. Fricke gel can be more preferred in terms of ease of production. In this study Fricke gels, containing $FeSO_4$ solutions at four different concentrations including $CaCl_2$ or gluconic acid, were produced. The produced gels were irradiated with x-rays at 0, 50, 100, 150, 200 and 250 cGy under 1 cm water equivalent phantom at 6 MV. The MR intensity values were linearly changed depending on the concentrations of the produced samples and the dose amount of the applied radiation. As a result, before a radiotherapy treatment the possible radiation dose distribution in the body of a cancer patient can be determined by these produced gels as a 3D dose imaging system.

The dose sensitivities of the gels can be improved by using $FeSO_4$ and gluconic acid at higher concentrations. $CaCl_2$ can be settled at higher concentrations. Therefore, gels containing at lower concentrations of $CaCl_2$ and higher concentrations of $FeSO_4$ can be researched. Furthermore gels can be developed with different additives. There is urgently need to improve these studies for the cancer patients.

Acknowledgment

This study is supported by Atatürk University with BAP project AU 2014/12.

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