Computer Methods and Programs in Biomedicine 159 (2018) 37–50

Contents lists available at ScienceDirect

Computer Methods and Programs in Biomedicine

journal homepage: www.elsevier.com/locate/cmpb

Monte-Carlo based assessment of MAGIC, MAGICAUG, PAGATUG and PAGATAUG polymer gel dosimeters for ovaries and uterus organ dosimetry in brachytherapy, nuclear medicine and Tele-therapy

Karim Adinehvand[a,*], Fereidoun Nowshiravan Rahatabad[b]

[a] Department of Medical Radiation Engineering, College of Engineering, Borujerd Branch, Islamic Azad University, Borujerd, Iran
[b] Department of Biomedical Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran

ARTICLE INFO

Article history:
Received 25 May 2017
Revised 11 January 2018
Accepted 22 February 2018

Keywords:
Polymer gel dosimetry
MAGIC and MAGICAUG
PAGATUG and PAGATAUG
Brachytherapy
Nuclear medicine
Tele-therapy

ABSTRACT

Background and objectives: Calculation of 3D dose distribution during radiotherapy and nuclear medicine helps us for better treatment of sensitive organs such as ovaries and uterus. In this research, we investigate two groups of normoxic dosimeters based on meta-acrylic acid (MAGIC and MAGICAUG) and polyacrylamide (PAGATUG and PAGATAUG) for brachytherapy, nuclear medicine and Tele-therapy in their sensitive and critical role as organ dosimeters.
Methods: These polymer gel dosimeters are compared with soft tissue while irradiated by different energy photons in therapeutic applications. This comparison has been simulated by Monte-Carlo based MCNPX code. ORNL phantom–Female has been used to model the critical organs of kidneys, ovaries and uterus. Right kidney is proposed to be the source of irradiation and another two organs are exposed to this irradiation.
Results: Effective atomic numbers of soft tissue, MAGIC, MAGICAUG, PAGATUG and PAGATAUG are 6.86, 7.07, 6.95, 7.28, and 7.07 respectively. Results show the polymer gel dosimeters are comparable to soft tissue for using in nuclear medicine and Tele-therapy. Differences between gel dosimeters and soft tissue are defined as the dose responses. This difference is less than 4.1%, 22.6% and 71.9% for Tele-therapy, nuclear medicine and brachytherapy respectively. The results approved that gel dosimeters are the best choice for ovaries and uterus in nuclear medicine and Tele-therapy respectively.
Conclusions: Due to the slight difference between the effective atomic numbers of these polymer gel dosimeters and soft tissue, these polymer gels are not suitable for brachytherapy since the dependence of photon interaction to atomic number, for low energy brachytherapy, had been so effective. Also this dependence to atomic number, decrease for photoelectric and increase for Compton. Therefore polymer gel dosimeters are not a good alternative to soft tissue replacement in brachytherapy.

1. Introduction

There are several dosimetry techniques used to determine the distribution of radiation dose during radiation treatment. Each dosimeter tool has a set of unique advantages and disadvantages. Gel dosimeters are inherent dosimeters for determining 3D dose distribution mediums with high spatial resolution unlike conventional dosimeters such as radioactive ionization chambers, TLD cards and radiography films [1,2]. The TLD or mini ionization chambers have weaknesses to measure very high doses with high dose gradients due to their finite size that measure the dose only at a single point [1]. Film batches can also offer 3D dose measurements by positioning film in multiple planes but accurate positioning of films in several layers can be a difficult and time consuming process. Therefore, the conventional dosimeters cannot be suitable for clinical brachytherapy [3].

Fricke gel and polymer gel dosimeters are currently two different types of gel dosimeters that can give us 3D dose distribution. But the polymer gel dosimeters maintain a high spatial integrity in comparison to the Fricke gel dosimeters [4]. Polymer gel dosimeters have several advantages such as high spatial resolution, feasibility of three-dimensional dosimetry and they act as a phantom as well as a detector and do not require the use of perturbation correction factor [5,6]. In this research we study two types of polymer gel dosimeters for different clinical applications. Calculation of

* Corresponding author.
E-mail address: K.adinehvand@iaub.ac.ir (K. Adinehvand).

https://doi.org/10.1016/j.cmpb.2018.02.013
0169-2607/

Table 1
Construction of polymer gel dosimeters based on meta-acrylic (MAGIC and MAGICAUG) and polyacrylamide (PAGATUG and PAGATAUG).

Material	W_C	W_H	W_N	W_O	W_S	$W_{Cu(II)}$	W_P	W_{Cl}	ρ $^{(g.cm-3)}$	Z_{eff}
MAGICAUG	0.167	0.0951	0.0358	0.7004	1.92×10^{-6}	3.81×10^{-6}	-	-	1.095	**6.9510**
PAGATAUG	0.1002	0.1016	0.0340	0.7656	-	-	1.43×10^{-4}	1.63×10^{-4}	1.0483	**7.0705**
MAGIC	0.0751	0.1062	0.0139	0.8021	2.58×10^{-6}	5.08×10^{-6}			1.06	**7.07**
PAGATUG	0.092	0.102	0.034	0.771	–	–			1.0653	**7.2884**

Table 2
Elemental composition of the tissues for ORNL phantom–Female.

Percent by weight			
Element	Soft tissue	Skeleton	Lung
H	10.454	7.337	10.134
C	22.663	25.475	10.238
N	2.490	3.057	2.866
O	63.525	47.893	75.752
F	0	0.025	0
Na	0.112	0.326	0.184
Mg	0.013	0.112	0.007
Si	0.030	0.002	0.006
P	0.134	5.095	0.080
S	0.204	0.173	0.225
Cl	0.133	0.143	0.266
K	0.208	0.153	0.194
Ca	0.024	10.190	0.009
Fe	0.005	0.008	0.037
Zn	0.003	0.005	0.001
Rb	0.001	0.002	0.001
Sr	0	0.003	0
Zr	0.001	0	0
Pb	0	0.001	0
Density (g/cm^3)	1.04	1.4	0.296
Z_{eff}	6.86134	–	–

absorbed dose distribution in patient and optimization in order to less sustaining injury of other organs especially sensitive reproductive organs, before radiotherapy, is one of the basic steps in treatment planning [7].

Many authors have investigated the water/tissue equivalency of gel dosimeters for photon irradiation [5,8–11].

There are several different scans in the nuclear medicine applications. Heart scans are the most common scan among other scans. In this scan, kidneys absorb highest amount of dose while they are near the generation organs (ovaries and uterus) [12]. For this reason, we consider the source positions have been placed in the kidneys in brachytherapy and kidneys are radiated in nuclear medicine and Tele-therapy.

As we mentioned above, the polymer gels can be used in medical phantoms as a valuable tool to determine 3D dose distribution in a medium. The polymer gel dosimeter can replace medical phantom materials in order to have similar features with soft tissue. This type of dosimeters can be considered as a suitable option for studying dose distribution in sensitive organs during radiation therapy and nuclear medicine. Received dose in sensitive organs have more important role during radiation therapy and nuclear medicine, so we intend to study the capabilities of polymer gel dosimeters in medical phantoms for evaluating absorbed dose of ovaries and uterus from right kidney during brachytherapy, nuclear medicine and Tele-therapy. In this work, using polymer gel dosimeters in medical phantoms for evaluating absorbed dose of ovaries and uterus irradiated from left kidney during brachytherapy, nuclear medicine and Tele-therapy is studied. Problem def-

Table 3
The output of simulations for polymer gel dosimeters during brachytherapy, nuclear medicine and Tele-therapy.

Source	Source Activity (MBq)	Location Source	Target Organ	Dose (rem/h)	Error	Dosimeter	Density (gr/cm^3)	$[\frac{Dose_{gel} - Dose_{soft\ tissue}}{Dose_{soft\ tissue}} * 100]$
^{125}I	1110	Right kidney	Ovaries	2.18E−2	0.0260	MAGIC	1.06	445
^{125}I	1110	Right kidney	Uterus	1.72E−2	0.0164	MAGIC	1.06	446
TC-99m	1110	Right kidney	Ovaries	7.13E−2	0.0111	MAGIC	1.06	22.29
TC-99m	1110	Right kidney	Uterus	6.29E−2	0.0071	MAGIC	1.06	22.85
Co-60	188E+6	Right kidney	Ovaries	6.94E−7	0.0587	MAGIC	1.06	0.72
Co-60	188E+6	Right kidney	Uterus	6.89E−7	0.0404	MAGIC	1.06	7.6
^{125}I	1110	Right kidney	Ovaries	5.16E−3	0.0442	MAGICAUG	1.095	29
^{125}I	1110	Right kidney	Uterus	4.43E−3	0.0248	MAGICAUG	1.095	40.63
TC-99m	1110	Right kidney	Ovaries	5.90E−2	0.0102	MAGICAUG	1.095	1.20
TC-99m	1110	Right kidney	Uterus	5.16E−2	0.0061	MAGICAUG	1.095	0.78
Co-60	188E+6	Right kidney	Ovaries	7.01E−7	0.0550	MAGICAUG	1.095	1.74
Co-60	188E+6	Right kidney	Uterus	6.40E−7	0.0401	MAGICAUG	1.095	0
^{125}I	1110	Right kidney	Ovaries	6.68E−3	0.0388	PAGATUG	1.0653	67
^{125}I	1110	Right kidney	Uterus	5.57E−3	0.0227	PAGATUG	1.0653	76.8
TC-99m	1110	Right kidney	Ovaries	6.06E−2	0.0102	PAGATUG	1.0653	3.9
TC-99m	1110	Right kidney	Uterus	5.30E−2	0.0061	PAGATUG	1.0653	3.5
Co-60	188E+6	Right kidney	Ovaries	6.33E−7	0.0569	PAGATUG	1.0653	−8.1
Co-60	188E+6	Right kidney	Uterus	6.30E−7	0.0405	PAGATUG	1.0653	−1.5
^{125}I	1110	Right kidney	Ovaries	6.15E−3	0.0410	PAGATAUG	1.0483	54.75
^{125}I	1110	Right kidney	Uterus	5.11E−3	0.0233	PAGATAUG	1.0483	62.22
TC-99m	1110	Right kidney	Ovaries	6.03E−2	0.0101	PAGATAUG	1.0483	3.43
TC-99m	1110	Right kidney	Uterus	5.33E−2	0.0060	PAGATAUG	1.0483	4.10
Co-60	188E+6	Right kidney	Ovaries	6.91E−7	0.0542	PAGATAUG	1.0483	0.29
Co-60	188E+6	Right kidney	Uterus	6.54E−7	0.0392	PAGATAUG	1.0483	2.19
^{125}I	1110	Right kidney	Ovaries	4.00E−3	0.0228	Soft Tissue	1.04	–
^{125}I	1110	Right kidney	Uterus	3.15E−3	0.0127	Soft Tissue	1.04	–
TC-99m	1110	Right kidney	Ovaries	5.83E−2	0.0046	Soft Tissue	1.04	–
TC-99m	1110	Right kidney	Uterus	5.12E−2	0.0027	Soft Tissue	1.04	–
Co-60	188E+6	Right kidney	Ovaries	6.89E−7	0.0557	Soft Tissue	1.04	–
Co-60	188E+6	Right kidney	Uterus	6.40E−7	0.0401	Soft Tissue	1.04	–