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Water equivalence of polymer gel dosimeters

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Abstract

To evaluate the water equivalence and radiation transport properties of polymer gel dosimeters over the wide range of photon and electron energies 14 different types of polymer gels were considered. Their water equivalence was evaluated in terms of effective atomic number (Z_{eff}), electron density (ρ_e), photon mass attenuation coefficient (μ/ρ), photon mass energy absorption coefficient (μ_{en}/ρ) and total stopping power $(S/\rho)_{tot}$ of electrons using the XCOM and the ESTAR database. The study showed that the effective atomic number of polymer gels were very close ($<1\%$) to that of water except PAGAT, MAGAT and NIPAM which had the variation of 3%, 2% and 3%, respectively. The value of μ/ρ and μ_{en}/ρ for all polymer gels were in close agreement ($<1\%$) with that of water beyond 80 keV. The value of $(S/\rho)_{tot}$ of electrons in polymer gel dosimeters were within 1% agreement with that of water. From the study we conclude that at lower energy (<80 keV) the polymer gel dosimeters cannot be considered water equivalent and study has to be carried out before using the polymer gel for clinical application.

Keywords: Gel dosimetry; Polymer gel; Three-dimensional radiation dosimetry; Tissue equivalence

1. Introduction

The potential benefits of highly localized conformal techniques such as Intensity Modulated Radiation Therapy (IMRT), Stereotactic Radiosurgery (SRS) and Stereotactic Radiotherapy (SRT) are greatly desirable. They include the reduction of radiation side effects in normal tissue and the ability to tailor the dose distributions to the treatment target volume with high uniformity and precision. These techniques provide complex three-dimensional conformal dose distributions. There are no dosimeters available in radiotherapy centers to measure three-dimensional dose distributions. The radiation induced chemical changes in gel dosimeters are the only method of measuring the three-dimensional dose distributions produced by IMRT, SRS and SRT techniques. Polymer gel dosimeters are formed by uniform dispersion of acrylic monomers in a water based matrix like gelatin. When the polymer gel dosimeter is exposed to radiation, radiation induced polymerization and cross-linking of the acrylic monomer takes place. As the result of this polymerization, the physical properties of the gel are altered. This property can be studied using magnetic resonance imaging (MRI) (Maryanski et al., 1993, 1994), optical CT scanner (Gore et al., 1996; Maryanski et al., 1996a,b), Raman spectroscopy (Baldock et al., 1998; Jirasek et al., 2001) and computed X-ray tomography (CT) (Hilts et al., 2000; Trapp et al., 2001; Hilts and Duzenli, 2004; Audet et al., 2002). Polymer gel dosimeters have several advantages including high spatial resolution, tissue equivalence (Maryanski et al., 1996a,b), 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. In radiotherapy dosimetry, to replace the existing dosimeter with polymer gels one should evaluate the water equivalence of the polymer gel before application.

The aim of this study was to evaluate the water equivalence and radiation transport properties of polymer gels over the wide range of photon and electron energies.

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In this study 14 different types of polymer gels were considered and their water equivalence is evaluated in terms of effective atomic number (Z_{eff}), electron density (ρ_e), photon mass attenuation coefficient (μ/ρ), photon mass energy absorption coefficient (μ_{en}/ρ) and total stopping power $(S/\rho)_{\mathrm{tot}}$ of electrons.

2. Material and methods

To evaluate the water equivalence of polymer gel dosimeters, 14 different types of polymer gel dosimeters were considered. Their chemical compositions are given in Table 1. Fundamentally polymer gel dosimeters are composed of a water based matrix like gelatin in which monomers are dissolved. The polymer gel called BANG-1 (Bis Acrylamide Nitrogen Gelatin) (Maryanski et al., 1994; Michael et al., 2000), PAG (Poly Acrylamide Gelatin) (Maryanski et al., 1993, 1994) contains acrylamide as a monomer and BANG-2 (Bis Acrylic acid Nitrogen Gelatin) (Maryanski et al., 1996a,b) contains acrylic acid as a monomer. These monomers are highly toxic, so the researchers replaced these monomers with less toxic monomers like N-vinyl pyrolidone in VIPAR (N-Vinyl Pyrolidone ARgon gel) (Kipouros et al., 2001; Pappas et al., 1999) and poly (ethylene glycol) diacrylate in PABIG (Poly (ethylene glycol) diAcrylate, BIS, Gelatin) (Sandilos et al., 2004) gel. Even though these monomers are less toxic, all these gel dosimeters have to be prepared in the hypoxic condition. Because these gel dosimeters are inhibited by oxygen, free oxygen has to be removed from the gel. After several years normoxic gel dosimeters like MAGIC (Methacrylic acid, Ascorbic acid in Gelatin Initiated by Copper) (Fong et al., 2001), HEAG

Table 1
Chemical composition (% weight fraction) of polymer gel dosimeter

Composition	BANG-1	BANG-2	PABIC	PAG	MAGIC	VIPAR	ABAGIC	PAGAT	HEAG	MAGAS	MAGAT	nMAG	nPAG	NIPAM
Water	89.0	88.0	87.26	88.0	82.8	87.23	82.5	89.0	0.89	83.0	83.0	86.0	87.0	89.0
Gelatin	5.0	5.0	4.9	6.0	8.0	4.91	8	5.0	0.05	8.0	8.0	8.0	6.0	5.0
BIS	3.0	3.0	3.92	3.0	–	3.93	4.5	3.0	0.03	–	–	–	3.0	3.0
Acrylamide	3.0	–	–	3.0	–	–	4.5	3.0	–	–	–	–	3.0	–
Acrylic acid	–	3.0	–	–	–	–	–	–	–	–	–	–	–	–
Ascorbic acid	–	–	–	–	0.0352	–	0.0352	–	–	0.880	–	–	–	–
$CuSO_4{\cdot}5H_2O$	–	–	–	–	0.002	–	0.002	–	–	–	–	–	–	–
Hydroquinone	–	–	–	–	0.2	–	0.2	–	–	–	–	–	–	–
PEGDA	–	–	3.92	–	–	–	–	–	–	–	–	–	–	–
N–Vinyl pyrolidone	–	–	–	–	–	3.93	–	–	–	–	–	–	–	–
MAA	–	–	–	–	9.0	–	–	–	–	9.0	9.0	6.0	–	–
NaOH	–	1.0	–	–	–	–	–	–	–	–	–	–	–	–
THP	–	–	–	–	–	–	–	1.906	–	–	1.906	0.38	0.953	1.906
NIPAM	–	–	–	–	–	–	–	–	–	–	–	–	–	3.0
HEA	–	–	–	–	–	–	–	–	0.03	–	–	–	–	–

Table 2
Elemental composition (% weight fraction), electron density (ρ_e e/m^3) and effective atomic number (Z_{eff}) of water and different polymer gel dosimeters

Material	w_H	w_C	w_N	w_O	w_{Na}	w_P	w_S	w_{Cl}	w_{Cu}	$\rho_e(\times 10^{29}$ e/m$^3)$	$\mathbf{Z_{eff}}$
Water	11.2	–	–	88.8	–	–	–	–	–	3.340	7.420
BANG–1	10.7685	5.6936	2.0063	81.5316	–	–	–	–	–	3.402	7.413
BANG–2	10.6369	5.6728	1.4152	81.7004	0.5748	–	–	–	–	3.432	7.454
PABIG	10.6454	6.8373	1.5649	80.9524	–	–	–	–	–	3.400	7.405
PAG	10.7367	6.2009	2.1804	80.882	–	–	–	–	–	3.452	7.405
MAGIC	10.5473	9.2231	1.3916	78.8373	–	–	0.0003	–	0.0005	3.529	7.374
VIPAR	10.7321	7.1825	2.0638	80.0217	–	–	–	–	–	3.395	7.391
ABAGIC	10.5263	0.8963	0.3105	77.4054	–	–	0.0003	–	0.0005	3.528	7.363
PAGAT	10.7257	6.2174	1.9688	80.2166	–	0.4064	–	0.4651	–	3.451	7.631
HEAG	10.7641	5.7243	1.4152	82.0964	–	–	–	–	–	3.436	7.419
MAGAS	10.5087	9.3591	1.3799	78.7523	–	–	–	–	–	3.454	7.372
MAGAT	10.522	9.5417	1.366	77.6988	–	0.4064	–	0.4651	–	3.435	7.596
nMAG	10.6775	7.5066	1.3868	80.2527	–	0.0822	–	0.0941	–	3.486	7.441
nPAG	10.7107	6.5251	2.1814	80.1385	–	0.5748	–	0.2371	–	3.451	7.518
NIPAM	10.8055	6.5998	1.7531	79.9702	–	0.4064	–	0.4651	–	3.447	7.624