



UNIVERSITI PUTRA MALAYSIA

**DEVELOPMENT AND CHARACTERIZATION OF NORMOXIC
POLYHYDROXYETHYLACRYLATE (nPHEA) GEL DOSIMETERS USING
MAGNETIC RESONANCE IMAGING (MRI) CLINICAL SCANNER**

MARYAM ERFANI HAGHIRI

FS 2009 7



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MAGNETIC RESONANCE IMAGING (MRI) CLINICAL SCANNER**

By

MARYAM ERFANI HAGHIRI

**Thesis submitted to the School of Graduated Studies, Universiti Putra
Malaysia, in Fulfilment of the requirement for the Degree of Master of
Science**

September 2009



In the name of Allah, the most gracious, the most merciful

الْحَمْدُ لِلَّهِ الَّذِي لَهُ مَا فِي السَّمَوَاتِ وَمَا فِي الْأَرْضِ وَلَهُ الْحَمْدُ فِي الْآخِرَةِ وَهُوَ
الْحَكِيمُ الْخَبِيرُ (١) يَعْلَمُ مَا يَلْجُ فِي الْأَرْضِ وَمَا يَخْرُجُ مِنْهَا وَمَا يَنْزِلُ مِنَ السَّمَاءِ وَمَا
يَعْرُجُ فِيهَا وَهُوَ الرَّحِيمُ الْعَفُورُ

Praise is to Allah, unto whom belonged whatsoever is in the heavens and whatsoever is in the earth. His is the praise in the Hereafter, and He is the Wise, the Aware. (1) He knows that which go down into the earth and that which cometh forth from it and that descend from the heaven and that which ascend into it. He is the Merciful, the Forgiving.

Saba, ayat (1) & (2)

DEDICATION

**TO THE MEMORY OF MY SWEETHEART EBRAHIM,
MY FATHER AND MY GRANDMA**

God bless them, Amin



Abstract of the thesis presented to the senate of Universiti Putra Malaysia in fulfillment of requirement for degree of Master of Science

**DEVELOPMENT AND CHARACTERIZATION OF NORMOXIC
POLYHYDROXYETHYLACRYLATE (nPHEA) GEL DOSIMETERS USING
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September 2009

Chairman: Professor Elias Saion, PhD

Faculty: Science

Polymer gel dosimeter is a three dimensional (3D) polymer gel system for recording radiation dose distribution in radiotherapy treatment planning. The dosimeter is based on polymerization of copolymers induced locally by free radicals, the products of water radiolysis. Interaction of free radicals with the monomer and crosslinker causes a breakage of double C=C bonds into single C-C bonds, leading to copolymerization between the two copolymers to form high density insoluble polymer in gelatin matrix and is normally achieved by purging nitrogen into the system to remove oxygen during preparation. In this work, new type of polymer dosimeter, i.e. the 'normoxic' polymer gels, is synthesized by adding oxygen scavenger to remove oxygen. The dosimeter is



based on polyhydroxyethylacrylate (nPHEA) gels containing 2-4% (w/w) 2-hydroxyethylacrylate (HEA) monomer, 2-4% (w/w) bisacrylamide (BIS) comonomer, 3-5% (w/w) gelatin, and 87-93% (w/w) water in normal atmospheric condition. The polymer gel phantoms were irradiated with beam doses up to 30 Gy using ^{60}Co teletherapy γ -ray source at a constant dose rate of 0.22 Gy/min.

The polymerization of nPHEA dosimeters was evaluated by means of magnetic resonance imaging (MRI) clinical scanner, which produced 3D optical density distribution and registered as MRI films. The gray scale of MRI images was measured using an optical densitometer. The optical density of the polymer gels was found to increase with increasing of absorbed dose and decreased with the increase of depth inside the phantom. The optical density was then converted to absorb dose by a mathematical relationship obtained from the experiment. The dose-depth maps for nPHEA gels were obtained for different concentrations of co-monomers, gelatin and at different beam doses. The results indicated that dose decreases of with decreasing of depth and gelatin concentration and increases with increasing of co-monomer concentrations. Finally the cross beam dose-depth map has been acquired by irradiating nPHEA phantom from two (3 cm x 3 cm) square γ -ray beams of 14 Gy and 25 Gy which perpendicular to each other. The results showed the distribution of 3D dose-depth profile that decreased with increasing depth and lower beam dose. One region of high dose

distribution in particular was seen in the overlapped beams, which in the actual clinical practices, it may represent a cancer volume that to be inactivated with higher dose than the surrounding healthy non-cancer tissues.



Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains

**PEMBANGUNAN DAN PENCIRIAN DOSIMETER GEL NORMOXIC
POLYHYDROXYETHYLACRYLATE (nPHEA) DENGAN MENGGUNAKAN
IMBASAN KELINIK PENGIMEJAN RESONAN MAGNET (MRI)**

Oleh

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Dosimeter gel berpolimer ialah system gel berpolimer tiga dimensi (3D) untuk merekodkan taburan dos sinaran dalam plan rawatan radiotrepi. Dosimeter ini berasaskan kepada pempolimeran copolymer yang dirangsang oleh radikal bebas yang terhasil semasa radiolysis air. Salingtindakan antara radikal bebas dengan monomer dan tautsilang menyebabkan terputusnya ikatan dedua C=C kepada ikatan tunggal C-C, lalu menghasilkan kopolimeran antara dua kopolimer dan membentuk satu polimer tak larut dan mempunyai ketumpatan tinggi dalam matrik gelatin yang lazimnya diperolehi semasa penyediaan dengan menyalurkan nitrogen dalam system untuk mengeluarkan oksigen. Dalam kajian ini satu dosimeter polimer baharu iaitu gel normoxic polimer telah disintesis dengan menambahkan anti oksigen untuk menyerap oksigen.



Dosimeter itu berasaskan gel polyhydroxyethylacrylate (nPHEA) yang mengandungi 2-4% (w/w) monomer 2-hydroxyethylacrylate (HEA), 2-4% (w/w) ko-monomer bisacrylamide (BIS), 3-5% (w/w) gelatin, and 87-93% (w/w) air dalam keadaan tekanan atmosfera. Fentom-fentom gel polimer digunakan dan disinarkan dengan dos sehingga 30 Gy menggunakan sumber sinar gama ^{60}Co jenis teletherapi pada kadar dos malar 0.22 Gy/min.

Pempolimeran dosimeter nPHEA dosimeters telah dianalisis dengan menggunakan pengimbas kelinik pengimejan resonan magnet (MRI) yang menghasilkan taburan ketumpatan optik 3D dalam film MRI. Skalar gray imej MRI telah diukur dengan menggunakan densitometer optik. Didapati ketumpatan optik bertambah dengan pertambahan dos terserap dan berkurangan dengan penambahan kedalaman fentom. Ketumpatan optik telah dipindahkan kepada dos terserap dengan menggunakan hubungan matematik yang diperolehi daripada eksperimen ini. Peta dos-kedalaman telah diperolehi pada kepekatan ko-monomer dan gelatin yang berbeza dan juga pada dos berbeza. Keputusan menunjukkan bahawa dos berkurangan dengan penambahan kedalam fentom dan kepekatan gelatin dan bertambah dengan kepekatan ko-monomer. Akhir sekali peta dos-kedalaman persilangan alur gama segiempat (3 cm x 3 cm) telah diperolehi daripada dos 14 Gy and 25 Gy berkeadaan mengcacang antara satu sama lain. Keputusan itu menunjukkan bahawa profil dos-kedalaman taburan 3D yang berkurangan dengan

pertambahan kedalaman dan dos alur rendah. Satu kawasan pada taburan dos tinggi didapati pada pertindihan dos alur dimana dalam amalan kelinik ia mewakili isipadu kanser yang perlu dimusnahkan keaktifannya pada dos lebih tinggi berbanding dos yang terima oleh tisu bukan kanser disekitarnya.

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I certify that a Thesis Examination Committee has met on 10th of September 2009 to conduct the final examination of MARYAM ERFANI HAGHIRI on her thesis entitled "Development and Characterization of normoxic Polyhydroxyethylacrylate (nPHEA) gel dosimeters using Magnetic Resonance Imaging (MRI) clinical scanner " in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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DECLARATION

I declare that the thesis is my original work except for quotations and citations, which have been duly acknowledgement. I also declare that it has not been previously or concurrently submitted for any other quantity at UPM or other institutions.

MARYAM ERFANI HAGHIRI

Date: 2 Oct 2009

TABLE OF CONTENTANTS

	Page
DEDICATION	iii
ABSTRACT	iv
ABSTRAK	vii
ACKNOWLEDGEMENTS	x
APPROVAL	xii
DECLARATION	xiv
LIST OF TABLES	xviii
LIST OF FIGURES	xix
LIST OF ABBRIVATIONS	xxii

CHAPTER

1	INTRODUCTION	
	1.1 Radiation Therapy treatment	1
	1.2 Objective of study	2
	1.3 Statement of the problem	3
	1.4 Significant of the study	4
	1.5 Outline of the thesis	5
2	LITERATURE REVIEW	
	2.1 Background of gel dosimetry	6
	2.1.1 Fricke gel dosimeter	6
	2.1.2 Polymer gel dosimeter	7
	2.1.3 Normoxic dosimeters	9
	2.2 Effective factors on polymer gel dosimeters	11
	2.2.1 Effect of oxygen	11
	2.2.2 Effect of light	11
	2.2.3 Effect of temperature	12
	2.3 Advantages of gel dosimetry	12
	2.4 Reaction process of polymerization	13
	2.5 Evaluation techniques	16
	2.5.1 Magnetic Resonance Imaging (MRI)	16
	2.5.2 Computed Tomography (CT) scanning	17
	2.5.3 Raman Spectroscopy	18
	2.6 Clinical applications of polymer gel dosimetry	21
	2.6.1 Brachytherapy	21



	2.6.2 Intensity Modulated Radiation Therapy (IMRT)	23
	2.6.3 Steotactic Radiosurgery and Radiotherapy	24
	2.6.4 Carbon ion Radiotherapy	25
	2.6.5 Boron neutron capture Therapy	25
3	THEORITICAL	
	3.0 Radiation Interaction with matter	27
	3.1 Type of ionizing radiation	28
	3.1.1 Direct ionizing radiation	28
	3.1.2 Indirect ionization	29
	3.2 Gamma Ray interaction	29
	3.3 Physical principle of radiation action	30
	3.3.1 Photoelectric Effect	30
	3.3.2 Compton Scattering	31
	3.3.3 Pair Production	33
	3.3.4 Triple Production	34
	3.4 Absorption	35
	3.5 Absorbed dose	37
	3.6 Radiation effects	37
	3.6.1 Ions and Excited molecules	37
	3.6.2 Radiolysis	40
	3.6.3 Recombination	40
	3.6.4 Polymerization	41
	3.6.5 Cross-linking	42
	3.6.6 Chain Scission	42
	3.6.7 Role of oxygen scavengers and oxygen	43
	3.7 Reaction Mechanism of THPC	44
	3.7.1 THPC reaction with gelatin	47
	3.7.2 THPC reaction with Acrylamide and BIS	47
	3.8 Magnetic Resonance Imaging (MRI)	48
	3.8.0 Introduction	48
	3.8.1 Basic MR physics	48
	3.8.2 Nuclear spin and behavior in magnetic field	49
	3.8.3 Resonance	51
	3.8.4 Magnetization and Relaxation	52
	3.8.5 Spin-echo	54
	3.8.6 Contrast-Image	55
	3.9 Optical Density	55
4	MATERIALS AND METHODS	
	4.1 Sample Preparation	57
	4.1.1 Synthesis of normoxic Polyhydroxyethylacrylate	



	(nPHEA) gels	57
4.2	Irradiation of polymer gels	60
4.3	Magnetic Resonance Imaging (MRI) scanning	63
4.4	Densitometer	66
5	RESULTS AND DISCUSSION	
5.0	Introduction	68
5.1	Mechanism of polymerization process normoxic PHEA Polymer gel	70
5.2	MRI scans at different beam doses and different composition Concentrations	72
5.3	Optical density versus depth of given dose	76
	5.3.1 Different concentration of co-monomers (HEA and BIS)	76
	5.3.2 Different concentration of gelatin	78
	5.3.3 Different concentration of cross-linker (BIS)	81
5.4	Changes in optical density versus dose	84
	5.4.1 Different concentrations of co-monomers (HEA and BIS)	84
	5.4.2 Different concentration of gelatin	86
	5.4.3 Different concentration of cross-linker (BIS)	88
5.5	Changes in absorbed dose versus depth	90
	5.5.1 Different concentration of co-monomers (HEA and BIS)	90
	5.5.2 Different concentration of gelatin	93
	5.5.3 Different concentration of cross-linker (BIS)	95
5.6	Cross dose map	97
6	CONCLUSION AND FUTURE WORKS	
6.1	Conclusion	102
6.2	Suggestions for future works	104
6.3	References	105
6.4	Appendix A	113
6.5	Biodata of Authur	115



LIST OF TABLES

Table	Label of tables	Page
2.1	Different formulations published for normoxic polymer gel Dosimeters	10
2.2	Vibrational band assignments for acrylamide (AAm),Bia-acrylamide and polyacrylamide	19
4.1	Compositions of normoxic PHEA gels based on 4% gelatin and 2-4% co-monomers	59
4.2	Compositions of normoxic PHEA gels based on 3-5% gelatin, 3%BIS, 3%HEA monomer	59
4.3	Compositions of normoxic PHEA gels based on 4%gelatin, 3%HEA, 2-4% BIS cross linker	59
4.4	Compositions of normoxic PHEA gel for cross-beam	60



LIST OF FIGURES

Figure	Page
2.1 Chemical structures of the some monomers used for polymer gel Dosimeters	8
2.2 Chemical structure of (a) acrylamide, (b) methacrylamide, (c) <i>N,N'</i> methylene-BIS-acrylamide, (d) polyacrylamide . After Billingham et al., 1972; Baldock et al., 1998b; Panajkar et al., 1997	15
2.3 FT-Raman spectra of PAG samples at different absorbed doses	20
2.4 Imaging of a brachytherapy phantom. After Deene et al., 2001	22
3.1 The decay scheme of ⁶⁰ Co isotope	29
3.2 Schematic diagram of photoelectric absorption	31
3.3 Schematic diagram of Compton process for gamma radiation	32
3.4 Schematic diagram of pair production and triple production process for γ -rays being interfered in the nucleus field and orbital electron to produce triplet particles	33
3.5 Schematic diagram of absorption effect	35
3.6 The total mass absorption coefficient of photon of energies below 100 MeV in iodine	36
3.7 The process of permanent main-chain scission of polyisobutylene	43
3.8 The energy separation ΔE between the two magnetic moment states	50
3.9 The mechanisms of spin states	50
3.10 The two states of a spin -1/2 sample in a magnetic field	53
3.11 The schematic diagram of reflection part of densitometer	55



4.1	Schematic diagram of sample preparation	58
4.2	Control panel & Electrometer - PYW UNIDOSE of Eldorado 8, ⁶⁰ Co teletherapy (Atomic Energy of Canada Limited)	61
4.3	Photograph of water phantom acrylic tank and Eldorado8, ⁶⁰ Co Teletherapy	62
4.4	Normoxic PHEA gel dosimeters which were irradiated with different doses (14 Gy and 25 Gy)	64
4.5	Clinical 1.5 T whole body MRI scanner (magnetom SP Siemens, Germany)	66
4.6	Radiological film obtained from MRI slice scans showing different contrast for different concentration and different doses: (a) 4% gelatin, 4%BIS, 4%HEA ; (b) 4%gelatin, 3%BIS, 3%HEA ; (c) 4% gelatin, 2%BIS, 2%HEA ; (d) 5%gelatin, 3%BIS, 3%HEA	67
4.7	Digital densitometer (Victoreen, model 07-440 ,USA)	71
5.1	Chemical structure of (a) 2-hydroxyethylacrylate (b) N,N'-methylene bis-acrylamide (c) Polyhydroxyethylacrylate	74
5.2	R2-weight images of irradiated PHEA at 0.7 cm depth for(a) 4%gelatin, 3%HEA, 4%BIS (b) 4%gelatin, 3% HEA, 3%BIS (c) 4%gelatin, 3%HEA, 2%BIS	78
5.3	Change the optical density of nPHEA resulting from (a)14 Gy beam source, (b) 25 Gy beam source versus depth at different concentration of BIS	78
5.4	Changes of optical density versus depth in nPHEA gels for (a) 14 Gy beam source and (b) 25 Gy beam source at different concentration of gelatin	80
5.5	Change in optical density of nPHEA resulting from (a) 8Gy beam source (b) 14Gy beam source (c) 20 Gy beam source (d) 25Gy beam source versus depth at different concentration of BIS	83
5.6	Change in optical density of nPHEA resulting from (a) 14Gy beam source, (b) 25Gy beam source versus dose at different co-monomer concentration	86



5.7	Change in optical density(OD) of nPHEAG versus dose resulting from (a)14Gy dose beam source and (b) 25Gy dose beam source at different concentration of gelatin	87
5.8	Change in optical density of nPHEA resulting from (a) 8Gy beam source (b 14Gy beam source (c) 20Gy beam source (d) 25Gy beam source versus dose at different concentration of BIS	90
5.9	Change in absorbed dose in nPHEA versus depth for (a)2%BIS,2%HEA, 4%gelatin ; (b) 3%BIS, 3%HEA,4%gelatin ; (c) 4%BIS, 4%HEA,4%gelatin Concentration	93
5.10	Change in dose versus depth in nPHEAG for different concentration of gelatin (a) 3%gelatin, 3%BIS, 3%HEA ; (b) 4%gelatin, 3%BIS,3%HEA; (c) 5%gelatin, 3%BIS, 3%HEA at two different dose beam source(14 Gy and 25Gy)	95
5.11	Change in absorbed dose in nPHEA versus depth for different concentration of BIS; (a) 4%gelatin, 2%BIS, 3%HEA concentration; (b) 4%gelatin, 3%BIS, 3%HEA concentration; (b) 4%gelatin, 4%BIS, 3% HEA concentration at different beam dose sources	97
5.12	R2-weight images of irradiated nPHEAG at 3%BIS, 3%HEA, 4%gelatin concentration irradiated form two sides perpendicular by square γ –ray to 14 Gy and 25 Gy beam source	98
5.13	Optical density of irradiated nPHEAG at 3%BIS, 3%HEA, 4%gelatin concentration irradiated form two sides perpendicular by square γ – ray to 14 Gy and 25 Gy beam source as a function of depth	99
5.14	Dose map of irradiated nPHEAG at 3%BIS, 3%HEA, 4% gelatin concentration irradiated from two sides by a square γ -ray to 14 Gy and 25 Gy beam source as function of depth	101

LIST OF ABBRIVATION

A	Atomic mass
AAm	Acrylamide
a.u	Arbitrary unit
B_0	Magnetic field
B_1	Magnetic induction
BIS	N,N'-methylene-bis-acrylamide
BNCT	Boron neutron capture therapy
C	Concentrations
c	Speed of light in vaccum ($c=3.0 \times 10^8 \text{ ms}^{-1}$)
CT	Computed tomography
D	Absorbed dose
D_0	Dose sensitivity
D_r	Dose range
E	Electrical field
E_e	Energy of recoil electron
E_b	Binding energy
\bar{E}	Mean energy deposited in the material
FID	Free Induction Decay
FOV	Field of view
Φ	Particle flounce
ν, f	Frequency
γ	Gamma radiation



h	Plank's constant
HEA	2-hydroxyethylacrylate
I_0	Intensity of incident beam
I	Nuclear spin
IMRT	Intensity-Modulated Radiation Therapy
K	Boltzman constant ($k=8.63 \times 10^{-5} \text{ev.molecule}^{-1} \cdot \text{k}^{-1}$)
LET	Linear Energy Transfer
N_A	Avogandro's number (6.022×10^{23} per mol)
NMR	Nuclear magnetic resonance
nPHEAG	Normoxic polyhydroxyethyl acrylate gel
m_0	Rest mass of electron
MNA	Malaysian Nuclear Agency
MRI	Magnetic resonance imaging
λ	Wavelength
μ	Linear absorption coefficient
μ/ρ	Mass absorption coefficient
π	Pi (=3.14)
q	Charge
Q_f	Quality factor
OD	Optical Density
RF	Radiofrequency
R_1	Spin-lattice relaxation rate
R_2	Spin-spin relaxation rate
SSD	Radiation source to sample distance

t	Time
T	Temperature, kinetic energy
T_1	Spin-lattice relaxation rate
T_2	Spin-spin relaxation rate
TE	Echo time
TR	Pulse repetition time
THP	Tris (hydroxymethyl) phosphonium
THPC	Tetrakis (hydroxymethyl) phosphonium chloride
THP ((HOCH ₂) ₃ P)	Formaldehyde
THPOH	Tetrakis (hydroxymethyl)phosphonium hydroxide
TLD	Thermo luminescence dosimeter
σ	Cross section
ω	Angular frequency
ω_0	Angular Larmor frequency
x	Depth, distance
x_0	Depth sensitivity
xr	Depth range