The comparison of absorbed dose measurements for water and artificial body fluid

T. Cakir^{1*}, A. Gur², A. Arasoglu³

¹Department of Radiation Oncology, Medical Faculty, Yuzuncu Yil University 65080, Van, Turkey ²Department of Physicalchemistry, Science and Art Faculty, Yuzuncu Yil University, 65080, Van, Turkey ³Department of Nuclear Physics, Science and Art Faculty, Yuzuncu Yil University, 65080, Van, Turkey

Background: Advances in radiation dosimetry concepts and the development of primary measurement standards based on absorbed dose to water over the last decades offer the possibility to calibrate ionisation chambers directly in terms of absorbed dose to water. The aim of this study is the investigation on utility of artificial body fluid (ABF) instead of water by comparing dosimetric measurements for radiotherapy between water and ABF which is more close to human tissue. Materials and Methods: The measurements were done using 60Co gamma source with a radiation field sizes of 5×5. 10×10. 15×15. 20×20 and 25×25 cm² at PTW Freiburg MP3 water phantom front surface. The comparisons of the dose measurements were obtained by using IAEA TRS-398 dosimetry protocols and Mephysto mc² dose analyzer program. Percent depth dose (PDD), dose profiles and penumbras are compared for water and ABF. Results: When the results of the PDD for water and ABF were compared, the maximum difference was observed in big field sizes. The difference in penumbras was found 2.3 mm averagely for depth of maximum dose (d_{max}). In addition same differences were observed between water and ABF when the dose profiles were compared. It is found that PDD values taken for water are good agreed with PDD values published in British Journal of Radiology (BJR) Supplement 25. Conclusion: Since the ABF is more equivalent to human tissue than water, it is suggested that advanced dosimetric studies should be performed with ABF instead of water. Iran. J. Radiat. Res., 2012; 10(3-4): 157-164

Keywords: Radiation dosimetry, absorbed dose measurement, artificial body fluid.

INTRODUCTION

A wide variety of ionising radiation effects on matter, whether they be physical, chemical or biological, have been suggested as a basis for radiation dosimetry $^{(1, 2)}$. These depend on the sort of changes imparted into a given material by the deposition of radiation energy, and if such changes are

measurable, stable and well characterised system may be practicable for radiation measurements ⁽³⁾. Absolute dosimetry of external beam radiotherapy is carried out by the use of ionization chambers. These chambers must be calibrated at a standard dosimetry laboratory before any use in dosimetry. clinical The expanded uncertainties in the determination of air kerma and absorbed dose to water are estimated to be 2%and 2.3%at approximately 95%confidence level, respectively ⁽⁴⁾. Absorbed dose to water is the quantity of interest to specify the amount of radiation to be used in radiotherapy and has the advantage that it can be measured more directly than the quantity air kerma. Advances in radiation dosimetry concepts and the development of primary measurement standards based on absorbed dose to water over the last decades offer the possibility to calibrate ionisation chambers directly in terms of absorbed dose to water (5)The ionization chambers should preferably be designed for absorbed dose measurements in water and the construction should be as homogeneous and water equivalent as possible ⁽⁶⁾. In order to be useful, radiation dosimeters must exhibit several desirable characteristics ⁽⁷⁾. For example, in radiotherapy exact knowledge of both the absorbed dose to water at a specified point and its spatial distribution are of importance, as well as the possibility of deriving the dose to an organ of interest in the patient ⁽³⁾. In this context, the

*Corresponding author:

Dr. Tahir Cakir, Department of Radiation Oncology, Medical Faculty, Yuzuncu Yil University 65080, Van, Turkey. Fax: +90 4322286396 E-mail: tcakir2003@yahoo.com desirable dosimeter properties will be characterized by accuracy and precision, linearity, dose or dose rate dependence, energy response, directional dependence and spatial resolution for water and ABF. In this paper the measurements have been done for PDD and dose profiles absorbed dose to both water and ABF. Although the water is assumed as the tissue equivalent in dosimetric measurements for radiotherapy, it is not true exactly.

Therefore, in this paper measurements of PDD and dose profiles for both water and ABF have been done separately. Assuming blood plasma is more equivalent to human tissue than water, artificial blood plasma solution has been prepared ^(8,9). The depth dose, dose profiles and beam quality parameters of different field sizes have been measured according to the IAEA TRS-398 with ⁶⁰Co photon unit by mephysto mc² dose analysis program in MP3 water phantom ^{(5,} ¹⁰⁻¹³⁾. The same of dosimetric parameters at the same measurement setup have been measured with distilled water. The measurements results obtained for both water and ABF have been compared.

MATERIALS AND METHODS

158

Prepared artificial body fluid

The ABF, known as metastable buffer solution by means of ion concentration, including the same chemical composition as human blood plasma, has been investigated (14-20). Taş (14) made up more suitable ABF as

blood plasma ion concentration changing the values HCO_3^{-} and Cl^{-} of ABF prepared by Kokubo ⁽¹⁸⁾. Pasinli *et al.* ⁽⁸⁾ prepared the Cl^{-} in concentration in blood plasma as 103 mM value. This prepared ABF showed resemble content to blood plasma for the first time, in terms of all inorganic ions. The patent of the chemical components used in this prepared ABF has been used ⁽²¹⁾. The ion concentrations of human blood and ABF have been shown in table 1.

The ABF was prepared using NaCl (sodium chloride), NaHCO₃ (sodium hidrocarbonate), KCl (kollium chloride), Na₂HPO₄.2H₂O (disodium hydrogen phospate di water), MgCl₂.6H₂O (magnesium chloride hekzo water), Na₂SO₄ (sodium sulfate), (CH₂OH)₃CNH₂ (hidroxylmethylamine methane), CaCl₂.2H₂O (calcium chloride di water) and HCl (hydrogen chloride). The chemical substances given in table 2 were dissolved in deionised water ⁽¹⁴⁾.

Purely prepared 750 ml of 1M HCl was added to the solution right away without adding CaCl₂.2H₂O, otherwise turbidity occur in the solution. The residual HCl was added to the solution during the titration. After the adding (CH₂OH)₃CNH₂, solution temperature was increased from medium temperature to body temperature 37 °C. At this temperature, pH kept as 7.4 with 1 M of HCl and deionised water is added to the solution up 50 L final volume to be able to prepare ABF. The physical intensity for ABF prepared in this way was found 1.075 g/cm³.

lon	Kokubo	Taş	Lac-SBFx1	Human Plasma
Na	142.0	142.0	142.0	142.0
Cl	147.8	125.0	103.0	103.0
HCO ₃	4.2	27.0	27.0	27.0
K+	5.0	5.0	5.0	5.0
Mg ²⁺	1.5	1.5	1.5	1.5
Ca ²⁺	2.5	2.5	2.5	2.5
HPO4 ²⁻	1.0	1.0	1.0	1.0
SO4 ²⁻	0.5	0.5	0.5	0.5

Table 1. Human plasma and ABF ions concentr	ration (mM) ^(8, 14, 18) .
---	--------------------------------------

Absorbed dose in water and artificial body fluid

Order	Chemical Substance	Amount (g/L)	g/50 L
1	NaCl	6.547	327.36
2	NaHCO ₃	2.268	113.40
3	KCI	0.373	18.66
4	Na ₂ HPO ₄ .2H ₂ O	0.178	8.90
5	MgCl ₂ .6 H ₂ O	0.305	15.26
6	CaCl ₂ .2H ₂ O	0.368	18.40
7	Na ₂ SO ₄	0.071	3.56
8	(CH ₂ OH) ₃ CNH ₂	6.057	302.86

Table 2. The chemical composition of ABF solution* (total volume=50 L) (14).

* patent pending. Turkish Patent İnstitute, Turkey, Appl.No.99-0037,11 January 1999.

Dosimetric measurements

Experimental depth and profile dose curves of this paper have been obtained in a Theratron1000E ⁶⁰Co radiotherapy unit provided by the Yuzuncu Yil University, medicine faculty, and department of Radiation Oncology, which has also provided all the facilities necessary to obtain measured data. Cobalt units use a 60Co radioactive source which is placed in the treatment head. To deliver dose to patients, the radiation beam provided from the source is collimated by jaws ⁽²²⁾. Because the energy of cobalt radiation is lower than those of linear accelerators, cobalt units are normally used to treat relatively shallow diseases such as those of the head and neck. One of the main reasons of using the Theratron1000E in this study was the fact that the Cobalt spectrum of the irradiation beam is already known and, therefore, easier to model.

The facility comprises a Theratron radiotherapy irradiator positioned to give a beam focused on a water tank. The cobalt unit has a collimator to provide rectangular fields from 5cmx5cm to 40cmx40cm. The measurements were performed in a detector placed in a motorized guide of the cubeshaped phantom with side 50 cm (PTW Freiburg MP3 water phantom) ⁽¹⁰⁾. Dose rates can be measured accurately in this phantom because precise positioning of high resolution detectors can be easily accomplished using a guide driven by

reinforced toothed belts. The used detector, a PTW Freiburg Semiflex 0.125cc thimble chamber, is able to register the dose contribution of photons (11, 23). The phantom has been irradiated with different field sizes, always maintaining the source-tosurface distance (SSD) equal to $100 \text{ cm}^{(5)}$. The detector movement for each of the collimator openings is controlled by the software, Mephysto mc² which has been programmed to make a high speed sweep, in both the beam direction and perpendicular to it, in order to obtain depth dose curve and dose profiles different at lavers. respectively.

The measurement of the absorbed dose to water and ABF was performed following the IAEA protocol (IAEA TRS-398) ⁽⁵⁾. Ion chamber was placed at in water and ABF. The field size at the surface of the phantom was 5×5 , 10×10 , 15×15 , 20×20 and 25×25 cm². The alignment of the radiation field and the water phantom was adjusted using three lasers. The absorbed dose was measured by absorbed dose analysis program by using software mephysto mc². The measurements were performed first in the distilled water instead of the discharge water then the ABF was placed in the phantom at the same setup.

RESULTS AND DISCUSSION

The measurement results of PDD, dose profiles and beam quality parameters

159

T. Cakir, A. Gur, A. Arasoglu

between ABF and water was compared. In addition, our PDD measurement results for water were compared with depth dose measurement results of BJR supplement 25 ⁽²⁴⁾ which accepted as reference literature for same setup. Results of the comparing PDD measurements values of ⁶⁰Co photons, in SSD=100 cm distance for water, whole measured fields with BJR 25 and our work have been stated below.

For 5×5 cm² field; differences until 20 cm depth was found too much below according to the 2% ⁽²⁵⁾ margin of tolerance while 25 cm depth was found 2.95%, for 10×10 cm²

field; differences until 20 cm depth was found too much below according to the 2% $^{(25)}$ margin of tolerance too while 25 cm depth was found 3.9%, 15×15 cm² and 20×20 cm² fields; whole differences until 25 cm depth was found too much below according to 2%, 25×25 cm² field; differences in 5, 15 and 20 cm depth was found below according to the 2% while 10 and 25 cm depth was found a few above 2% (figure 1a, 1b, 1c, 1d,1e and table 3).

Normally, the difference between absorbed dose measurement values with the same radiation supply and in the same



Figure 1. Percent depth dose measured by water and ABF in water phantom for a for 5×5 cm² (A); 10×10 cm² (B); 15×15 cm² (C); 20×20 cm² (D) and 25×25 cm² (E) field size with ⁶⁰Co teletherapy machine.

Iran. J. Radiat. Res., Vol. 10 No. 3-4, December 2012

160

material is unexpected. However, since the collimator systems of devices in which there is radiation supply differs from each other partially, this difference is usual. But there is not any difference for water and ABF because of the same device is used for them. As a result, our PDD values in all field sizes and depths have been found compatible with the reference values of BJR Supplement 25. There was not a very good agreement between PDDs of ABF and water in 5×5, 10×10, 15×15, 20×20 and 25×25 cm^2 size fields. Some differences which are

unignorable values such as %2.42-13.36 have been observed for all field sizes and depths (table 3). But it was not observed remarkable differences between the maximum dose depths (d_{max}) of ABF and water (figure 1a - e).

Table 3 shows the percentage of differences for the PDDs in fields 5×5 , 10×10 , 15×15 , 20×20 and 25×25 cm². It is seen from Table 3, the percentage of difference increase for the PDDs between water and ABF when the depth and field size were increased.

Table 3. Percentage of differences (differences %) of percent depth doses values between	n water and ABF for all field sizes and 5,
10, 15, 20, 25 cm depths.	

Donth	BID 35 ⁽²⁴⁾	Watar	ADE	Difference %	Difference %
(cm)				Water-BIR 25	Water-ABF
(em)	100	Fi	eld 5x5 cm^2		Water Abi
5	76.70	77.02	75.20	0.42	2.42
10	E2 20	E2 24	51.04	0.07	4.21
10	33.30	35.54	51.04	0.07	4.51
15	36.50	36.51	34.29	0.03	6.08
20	24.90	24.62	22.88	1.14	7.07
25	17.10	16.61	15.43	2.95	7.10
		Fie	ld 10×10 cm	1 ²	
5	80.40	80.23	78.08	0.21	2.75
10	58.70	58.71	55.96	0.02	4.68
15	41.60	41.52	38.98	0.19	6.12
20	29.30	29.14	27.08	0.55	7.07
25	20.80	20.06	18.56	3.69	7.48
		Fie	ld 15×15 cm	1 ²	
5	82.00	81.91	79.86	0.11	2.57
10	61.60	61.53	58.60	0.11	4.76
15	44.90	44.61	42.05	0.65	5.74
20	32.40	32.12	29.59	0.87	7.88
25	23.40	23.06	19.98	1.47	13.36
		Fie	ld 20×20 cm	1 ²	
5	83.00	82.11	80.02	1.08	2.61
10	63.30	62.60	59.63	1.12	4.74
15	47.10	46.63	43.31	1.01	7.12
20	34.50	34.12	31.11	1.11	8.82
25	25.40	24.92	22.16	1.93	11.08
Field 25×25 cm ²					
5	83.40	82.62	80.29	0.94	2.90
10	64.40	62.64	60.27	2.81	3.78
15	48.60	47.91	44.39	1.44	7.35
20	36.00	35.53	32.10	1.32	9.65
25	26.80	26.10	22.88	2.68	12.34

Iran. J. Radiat. Res., Vol. 10, No. 3-4, December 2012

T. Cakir, A. Gur, A. Arasoglu

Dose profiles were obtained for each field in the depths of d_{max} (0.5), 5, 10, 15 and 25cm. It is observed that there was not very good agreement between dose profiles of ABF and water in 5×5, 10×10, 15×15, 20×20 and 25×25 cm² size fields (figure 2a, 2b, 2c, 2d, 2e).

Dosimetric penumbra width is defined as lateral distance between 80% and 20% positions of the dose values ⁽³⁾. Different values of dosimetric penumbra were obtained using dose profiles at the depth of d_{max} for water and ABF. It was seen that there were differences between calculated penumbra values of ABF and water. These differences are more than 2 mm for all field sizes (table 4). It is seen that penumbra is bigger than acceptable value of 2 mm ⁽²⁵⁾. The reason of the bigger penumbra values of ABF from water is that density of ABF is bigger than water and count of scattered photon is directly proportional with density. Because; when the count of photons that made Compton interaction (dn) divided into fraction of photon (n), the equation is given by (dn/n=N_A .p.(Z/A). σ_e .dx) ⁽²⁶⁾. (N_A: the count of Avogadro, ρ : density of absorbent material, σ_e : cross-section, dx: distance obtained in absorbent material of photon).



Figure 2. Dose profile measured by water and ABF in water phantom for $5 \times 5 \text{ cm}^2$ (A); $10 \times 10 \text{ cm}^2$ (B); $15 \times 15 \text{ cm}^2$ (C); $20 \times 20 \text{ cm}^2$ (D) and $25 \times 25 \text{ cm}^2$ (E) field size and d_{max} (0.5), 5, 10, 15, 25 cm depths with ⁶⁰Co teletherapy machine.

162 Iran. J. Radiat. Res., Vol. 10 No. 3-4, December 2012

Absorbed dose in water and artificial body fluid

Field Size (cm ²)	Penumbra water (mm)	Penumbra ABF (mm)	Difference (mm)
5×5	111.90	14.22	2.32
10×10	112.86	14.97	2.11
15×15	113.36	15.62	2.26
20×20	113.83	16.23	2.40
25×25	114.30	16.71	2.41

Table 4. Differences of penumbra values between water and ABF at the depth of d_{max} for all field sizes.

CONCLUSION

Although the water is accepted as an equivalent value of tissue in terms of absorption and dispersion features in dosimetric measurements for radiotherapy applications ⁽³⁾, from the results presented, it is obvious that the water has not an equivalent value of human tissue because of the presence of various elements in the tissue and its higher density. Therefore, considerable differences have been found between PDD, dose profile and penumbra in dosimetric studies performed for water and ABF. According to our study, the main reason for this difference might be due to the interaction of photon with water (which is composed of only two elements), and the interaction of photon with ABF (which is composed of 11 different elements). In addition, the characteristics of absorbed dose and dose dispersion are different because of the differences in density of water and ABF. The reason of higher values of penumbra in ABF compared to water might be due to the density of electron which has been snapped of ABF composed of 11 elements. much higher than the water.

ACKNOWLEDGEMENT

This research supported by Yuzuncu Yil University, Head of the Scientific Research Projects (Project No: 2010FBED057).

REFERENCES

1. Attix F.H (1986) Introduction to Radiological Physics and Radiation Dosimetry, Wiley, New York.

- 2. Horton J (1987) Handbook of Radiation Therapy Physics, Prentice Hall, New York.
- Khan FM (2003) The Physics of Radiation Therapy, Lippincott, Williams and Wilkins, Baltimore, MD.
- Solimanian A and Ghafoori M (2010) Standard calibration of ionization chambers used in radiation therapy dosimetry and evaluation of uncertainties. *Iran J Radiat Res*, 8:195-199.
- International Atomic Energy Agency (2000) Absorbed Dose Determination in External Beam Radiotherapy, Technical Reports Series No. 398, IAEA, Vienna.
- Villarreal-Barajas JE, Gonza lez-Marti nez PR, Uren a-Nun ez F, Marti nez-Ayala L, Tovar Mun oz VM (2002) Intercomparison of absorbed dose to water measurements For ⁶⁰Co gamma rays using fricke, alanine and radiochromic dye film dosimetry. *Radiation Protection Dosimetry*, **101**: 1–4, pp. 449–451.
- International Organization for Standartization (1992) Guide to Expression of Uncertainty in Measurement, ISO, Geneva.
- Pasinli A and Aksoy RS (2010) Hydroxyapatite for artificial bone applications. *Electronic Journal of BioTechnol*ogy, 1: 41-51.
- Pasinli A, Yüksel M, Çelik E, Şener S, Taş AC (2010) A new approach in biomimetic synthesis of calcium phosphate coatings using Lactic acid-Na lactate buffered body fluid solution, Acta Biomaterialia, 6: 2282-2288.
- 10. Ptw-Freiburg (2005) TBA Systems Catalog.
- 11. Ptw-Freiburg (2009) Ionizing Radiation Detectors.
- 12. Ptw-Freiburg (2006) User Manual Semiflex Ionization Chambers.
- International Atomic Energy Agency (1987) Absorbed Dose Determination in Photon and Electron Beams, Technical Reports Series No. 277, IAEA, Vienna.
- Taş AC (2000) Synthesis of Biomimetic Ca-Hydroxyapatite Powders at 37°C in Synyhetic Body Fluids, *Biomaterials*, **21**: 1429–1438.
- Taş AC (1998) İn situ coating of calcium hydroxyapatite on titanium or stainless steel surfaces at 37°C in synthetic body fluids, IV Eskisehir-Turkey. *Ceramics congress, Proceedings Book,* 2: 661-667.
- Li P, Kangasniemi I, de Groot K, Kokubo T (1994) Bonlike HA induction by a gel-derived Titania on a titanium substrate. *Journal of American Ce*, Soc, **77**: 1307-1312.
- 17. Neuman W and Neuman M (1958) The chemical dynamics of bone mineral. Chicago: *University of Chicago Press, p. 34.*
- Kokubo T (1998) Apatite formation on surfaces of ceramics, metals and polymers in body environment. *Acta materials*, **146**: 7, pp, 2519-2527.

T. Cakir, A. Gur, A. Arasoglu

- Kokubo T (1990) Surface chemistry of bioactive glass ceramics. J of Non Cryst Solids, 51: 120-138.
- Ohtsuki C, Kokubo T, Yamamuro T (1992) Mechanism of HA formation of CaO-SiO2-P2O5 glasses in simulated body fluid. J. of Non-Cryst Solids, 143: 84-92.
- Pasinli A, Yuksel M, Havitcioglu H, Tas AC, Aksoy RS, Celik E, Yildiz H, Toparli M, Canatan A, Sener S (2009) Calcium phosphate coating of Ti6Al4V by a Na-lactate and Lactic Acid-buffered body fluid solution. *PCT Patent*, *Appl. No: WO 2009/145741 A2.*
- 22. Van Dyk J (1999) Modern Technology of Radiation Oncology: A Compendium for Medical Physicists and Radiation Oncologists, *Medical Physics Publishing*, Madison.
- 23. Berlyand AV, Berlyand VA, Yu IB (2010) National primary standard for units of absorbed dose rate of photon and electron radiation, improvements and results of key comparisons. *Measurements Techniques*, **53**: 2.
- BJR Suppl. 25 (1996) Central axis depth dose data for use in radiotherapy: British Journal of Radiology Supplement 25. London.
- 25. International Atomic Energy Agency (1987) Absorbed Dose Determination in Photon and Electron Beams Radiotherapy, Technical Reports Series No. 277, IAEA, Vienna.
- Cottingham WN, Greenwood DA (2001) An Introduction to Nuclear Physics. 2nd edition, P.199-207, Cambridge University press.

Iran. J. Radiat. Res., Vol. 10 No. 3-4, December 2012