Depth dose measurement in water phantom for two X-ray energies (6MeV and 10MeV) in comparison with actual planning

Raghdah H. Hasan[1], Samar I. Essa*[1], Manwar A. AL-Naqqash[2]

[1]Department of Physics, College of Science, University of Baghdad, Baghdad. Iraq
[2]Department of Surgical, College of Medicine, University of Baghdad, Baghdad. Iraq

Abstract

The purpose of this study is to measure doses delivered at different depths in water phantom at vertical position in comparison with the actual planning in order to verify the dose delivered to the tumor in addition to the measurement of the effect penumbra dose to assess the dose leaking to the healthy soft tissue.

Percentage depth dose (PDD) values was measured at field sizes $(5\times5, 10\times10, 15\times15,$ and $20\times20)$ cm^2, and the depth dose was measured between (0-16) cm deep at 4cm intervals, for both energies 6 MeV and 10 MeV X-ray beam. Other readings were taken at different distances 1cm and 2cm outside of the actual beam in orthogonal directions at depth of 4 cm. These measurements were designed to measure the penumbra dose produced outside the central beam.

Results show that the high similarity between water phantom and actual tissue for this reason water is taken as phantom for Quality Assurance (QA) and calculation the depth dose. The similar results may appear strange as the actual planning depth dose is taken in the chest wall where there is bone and soft tissue. The increase in the field size, increases the percentage of surface dose, this could be caused by an increase in the amount of scattering in the larger fields. There is almost no difference in depth dose between homogenous and non homogenous planning also similar to the water phantom. Because of higher photon energy 6MeV and 10MeV the bone has no influence in absorption from the soft tissue. A slight change in the depth dose with increase in the field size may be caused by the scattered radiation.

Keywords: higher photon energy, water phantom, actual planning.

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قياس الجرعة العميقة في الوسط المائي لطاقتي الأشعة السينية (10MeV و6MeV) بالمقارنة مع التصميم العلاجي الحقيقي للمرضى

رغدة حارث حسن[1]، سمر عمران عيسى*[1]، منور عبد الاله النقاش[2]

[1] قسم الفيزياء، كلية العلوم، جامعة بغداد، بغداد، العراق
[2] قسم الجراحة، كلية الطب، جامعة بغداد، بغداد ، العراق

الخلاصة

الغرض من هذه الدراسة هو قياس الجرعات المتولدة في وسط مائي على أعماق مختلفة في الوضع الرأسي ومقارنتها مع التصميم العلاجي الحقيقي للمرضى من أجل التحقق من الجرعة التي يتسلمها الورم بالإضافة إلى قياس تأثير منطقة شبه الظل لتقييم الجرعة المتسربة الى الانسجة السليمة.

تم قياس النسبة المئوية لجرعة أشعة X (PDD) على مساحات مختلفة   (5×5,10×10,15×15, and 20×20)سم ^{2} ، كما وتم قياس الجرعة على اعماق مختلفة تتراوح بين (0−16) سم وعلى بعد 4 سم ، لكلا الطاقات   10 MeV و 6 MeV للأشعة السينية. تم أخذ قراءات أخرى على مسافات مختلفة 1 سم و 2 سم

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*Email: samaromran2000@gmail.com

خارج الحزمة الفعلية في اتجاهات متعامدة على عمق 4 سم وذلك لقياس جرعة شبه الظل المتولدة خارج
الحزمة المركزية.

أظهرت النتائج أن التشابه الكبير بين الوسط المائي والتصميم العلاجي الحقيقي للأنسجة كان سببا في
اخذ الماء كوسط لضمان الجودة (QA) وحساب جرعة العمق. التشابه قد يبدو غريبا حيث ان جرعة العمق
للتصميم العلاجي الفعلي مأخوذة في جدار الصدر حيث يوجد عظم وأنسجة رقيقة. ان الزيادة في مساحة
الأشعة ، تزيد من النسبة المئوية للجرعة السطحية ، وهذا يمكن أن يكون بسبب زيادة كمية التشتت بزيادة في
سعة الأشعة الساقطة . لا يوجد فرق في الجرعة العميقة بين التخطيط المتجانس وغير المتجانس على وجه
التقريب والذي يشبه أيضًا الوسط المائي. بسبب ارتفاع طاقة الفوتون 6MeV و10MeV ، فان العظم لا
يختلف في الامتصاص عن الأنسجة الرقيقة. قد يحدث تغير طفيف في عمق الجرعة مع زيادة في حجم
الاشعة وذلك بسبب تشتت الاشعاع.

1- Introduction

After X-rays was discovered by Roentgen in 1895, ionization radiations have been applied in many areas of industry and medicine to the benefit of mankind [1].
There are many types of cancer treatment. The types of treatment depends on the type of cancer and how advanced it is [2].

Different procedures are used in tumor treatment including surgery, chemotherapy, radiotherapy or combination between different modalities such as chemo-radiotherapy. The radiation quality, intensity and the doses delivered to the tumor are also different depending on the type of the tumor and location [3].

Planning is very important in the treatment with radiation. When irradiate the tumor we try to inflict the maximum damage (via high dose) to the tumor with minimum dose given to the healthy tissue and the skin in the case of external treatment. For this reason machines generating X-ray and the treatment technique have been changed and improved several times such as increasing energy filtration and the improvement in the X-ray machine led to manufacture the linear accelerator (LINAC). This study was carried out on a water phantom using linear accelerator at energy   (6 MeV and 10MeV [4].

Absorbed dose in the body is dependent on depth, field size, beam energy and source to surface distance (SSD). Measurement of absorbed dose is performed using water and actual planning, which is kept perpendicular to the path of beam. This measurement is expressed as percent of dose which gives a unique value for a certain set of parameters like beam energy, depth, SSD and field size [5].

2- Experimental details

The LINAC machine was located in the Oncology department Baghdad Teaching Hospital, Medical City/ Baghdad, type Elekta. The system is capable of generating X-rays in the range of megavoltages. The X-ray qualities used in the department for daily radiation therapy are 6MeV and 10 MeV. The measurements were carried out at source surface distance "SSD" of 100 cm. From water phantom surface which is usually used for measuring basic dose distribution because of its similarity to human soft tissue due to its, approximately density, average atomic number and number of electrons per gram also it is universally available with reproducible radiation properties. The water tank (phantom) is large enough to allow full photon scatter to be measured. The applicator was positioned just at the surface of the water with the central axis precisely over the ionization chamber's sensitive volume.   The dose was taken at the surface of the phantom material and on depth started from (0-16) cm deep at 4cm intervals. These values of PDD were different for different field sizes $(5\times5, 10\times10, 15\times 15,$ and $20\times20)$ cm^2. Data on dose distribution are almost entirely derived from measurements in phantoms, and then are used in a dose calculation system devised to predict dose distribution in an actual patient.

These measurements were taken when the dosimeter ionization chamber is positioned at the central beam. Other measurements were taken at different distances outside the beam in orthogonal directions at depth of 4 cm. These measurements were designed to measure the penumbra dose produced outside the central beam.

3- Results

The depth dose of photon beams in any medium can be evaluated with the different parameters, which exhibit the attenuation in its primary intensity. Usually the absorbed dose is described as

Percent Depth Dose, which is a function of depth ***d***, field size ***r*** and Source to Surface Distance (SSD) ***f***, is as follows [6]:

$$P(d, r, f) = 100 \cdot \left(\frac{f + d_m}{f + d}\right)^2 \cdot e^{-\mu(d-d_m)} \cdot K_s$$

K_s is the scattering component, d_m depth of maximum dose, linear attenuation coefficient (μ). This indicates the three governing rules of photon beam attenuation, inverse square law, exponential attenuation, and scattering component. This is why Percent Depth Dose uniquely varies with depth due to attenuation, with SSD due to inverse square law, and with field size due to scattering effect.
Percentage depth dose (PDD) in the water phantom and its comparison with actual planning (homogenous and non -homogenous) were measured at field sizes ($5\times5, 10\times10, 15\times15$, and 20×20) cm^2. The depth dose was measured between (0-16) cm deep at 4cm intervals.

In our results found a high similarity between water phantom and actual tissue as illustrated in Table-1, for this reason water is taken as phantom for Quality Assurance (QA) and calculation the depth dose. The similar results may appear strange as the actual planning depth dose is taken in the chest wall where there is bone and soft tissue and we may expect different absorption in bone than soft tissue but this is not true for high energies where the Compton effect is predominate interaction although are dealing with energy exceeds the pair production interaction threshold but it is still unimportant as it needs higher nuclear charge which need higher atomic number and because the human tissue has low atomic number in general pair production is not important only at high x-yay energies about 25-30MeV. So soft tissue contains high proportion of hydrogen as it contains more than 75% water and Compton interaction will be high because of hydrogen has about double electron density of all other elements so higher Compton interaction will occur, in this regard although the bone density is higher then soft tissue but it does not contain hydrogen so the photon absorption becomes similar to the soft tissue.

In actual planning there is a slight increase in the PDD with the increase in field size for both energies 6MeV and 10MeV and this is similar to what was found in the water phantom. The reason may be related to the scatter radiation i.e. an increase in the scatter radiation with the increase in the field size (Table-1)

Table 1-PDD of water phantom and actual planning for the chest for (6MeV) and (10MeV), with different field sizes

Field size (5×5)cm^2					
Energy (6MeV)			**Energy (10MeV)**		
Depth (cm)	**Phantom water**	**Actual planning**		**Phantom water**	**Actual planning**	
		(non homogenous)	**homogenous**		**(non homogenous)**	**homogenous**
0	42.43	38.3	37	29.95	29.68	29
4	90.65	89.8	89.3	95.10	97.1	97.5
8	72.81	72.4	71.6	78.79	80	79.8
12	57.96	57.6	57.2	64.81	65.2	65.3
16	46.25	45.7	44.8	53.21	53.1	52.6
Field size (10×10)cm^2					
Energy (6MeV)			**Energy (10MeV)**		
0	47.62	42.8	42.1	38.01	36	35.5
4	91.16	90.4	90.2	94.90	95.7	96.8
8	75.42	74.8	73.6	80.13	80.4	80.4
12	61.55	60.7	59.8	67.01	66.6	66.8
16	49.98	49	47.6	55.93	55	54.5
Field size (15×15)cm^2					
Energy (6MeV)			**Energy (10MeV)**		
0	50.36	44.8	41.1	40.88	37.6	38.2

4	91.79	91	90.9	94.76	95.5	96.3
8	76.96	76.1	74.9	80.85	81.1	80.8
12	63.60	62.7	61.6	68.35	68	67.7
16	52.32	51.2	49.6	57.58	56.7	55.8
Field size (20×20)cm²						
Energy (6MeV)			Energy (10MeV)			
0	54.75	48	46.3	46.47	39.8	39.5
4	92.10	92.2	90.9	94.45	94.9	95.8
8	77.72	77.8	75.5	80.99	81.1	80.8
12	64.91	64.7	62.7	68.95	68.6	68.2
16	53.88	53.3	51	58.40	57.6	56.6

The deeper the radiation in the tissue the lesser the depth dose, and this is resulted from the attenuation and inverse square law.

Out of field size (the X-ray field outside the field size governed by collimator borders) for (6MeV), measured in orthogonal directions the (X-axis and Y–axis)

The penumbra is defined as arbitrarily defined as the distance for the dose to fall off from 90% of the central axis value to 10% of the central axis value, from the beam size as a function of depth and field size for 6MeV X-rays are shown in Table-2, the increasing photon energy, penumbra also increases with depth in water and field size.

Table 2-Out of field (6MeV) , for the X–axis and Y-axis)

Field size (5×5) cm²		
Energy (6MeV) for (X-axis)		
Depth (cm)	Dose% at 1cm	Dose% at 2cm
0	2.33	1.57
1	3.46	1.52
2	4.32	1.83
3	5.04	1.57
4	5.29	1.77
Energy (6MeV) for (Y-axis)		
0	6.69	1.84
1	10.42	2.05
2	12.2	1.99
3	12.79	2.16
4	13.32	2.37

4- Discussion

Cancer can be treated in several ways such as surgery or chemotherapy, radiotherapy and combination of these modalities. Radiotherapy is used for kill tumor cells, the problem in using radiotherapy is killing not only cancer cell but also healthy tissue. One of most important outcome of research in radiotherapy together with x-ray machine design is to protect the healthy tissue from x- ray dose [7]. It is essential to measure the dose inside the patient accurately i.e. how much dose will be deposited in the tumor and how much dose will be delivered to the healthy tissue from primary and scatter radiation. This is a complicated problem as measurement of the dose directly in the patient is impossible instead a complicated equations for dose calculation and we usually able to measure the dose by using tissue equivalent phantom medium such as water [8].

Changing the exposure parameters can change the extent of the absorbed dose and consequently PDD, in addition to the change in other parameters such as the amount and the angle of scatter radiation.

By changing the field size for the same exposure time can see a slight increase in the PDD for both energies (6MeV and 10 MeV), as shown in Table-1, the increase in the surface dose appeared slightly more on the lower X-ray energy by 42.43%,47.62%,50.36%,54.75%. This increase may be attributed

to the fact that the higher X-ray energy lead to scatter more in the foreword than the lower energy i.e. more back scatter radiation can reach the surface in the case of low energy than the high energy [9].

The reason of using high energy is to spare the healthy tissue closer to the surface from damage particularly the skin through the protection of its stem cells, the higher the energy the deeper the maximum dose or the dose buildup this is apparent on the maximum PDD for 6 MeV, and 10 MeV X-ray ,this behavior can be attributed to the mean free path distance, which increases with the increase of energy and the increased distance for energy deposition for the secondary electrons meaning that the average distance between an interaction and the succeeded or next one is increased with increase of energy.

One of the disadvantage of the scattered radiation is the increased dose to tissues outside the field, to the healthy tissue which we always avoiding dose to it , in other words, the lesser the dose to the healthy tissue the better the treatment , so the higher the X-ray energy the less the scatter outside the field and the dose measurements outside the field is usually low. An increase in photon energy can give higher dose at larger depths with deeper maximum depth dose, as shown in Table-2.

At high photon energy 6MeV the interactions are pair production and Compton Effect where the former is of almost of no importance in soft tissue as the soft tissue is of low atomic number.

As Compton Effect interaction depends on electron density it will interact more with hydrogen than other materials because the hydrogen has almost double electron density than the other elements [10], and because bone has low hydrogen content (than soft tissue) it shows low X-ray absorption at high energies where photoelectric effect is not involved. For this reason the X-ray will penetrate the bones almost the same as soft tissue at such high energy, consequently less interaction and less secondary electrons resulting in less dose to the soft tissue in contact with the bone.

Conclusions
1- Increases field size increasing surface dose and this is attributed to the scatter radiation.
2- There is almost no difference in depth dose between homogenous and non homogenous planning also similar to the water phantom.
3- Due to higher photon energy 6MeV and 10MeV the bone absorption has no difference from the soft tissue.

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