Malaysian Journal of Science **21A**: 151-156 (2002)

The use of water phantoms in quality control of general x-ray machine for diagnostic radiology

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ABSTRACT In Malaysia, quality control (QC) measurements on medical diagnostic x-ray machines has to be carried out by a license class H holder, issued by the Ministry of Health under the Atomic Energy Licensing Act 1984. Certain QC measurement procedures for a general purpose diagnostic x-ray machine has to be performed under real clinical conditions which require the use of a phantom as a substitute of a human body. This includes in testing of automatic exposure control (AEC) and in the measurement of scattered radiation. Various types of phantom are used in diagnostic radiology for these purposes. A simple water phantom is introduced to represent an adult patient, which of course, produce interactions with radiation similar to that of a human being. In this paper the significant radiological effect of utilizing the simplified water phantom as compared to already an established phantom used for quality control purposes is investigated and will be presented in brief.

(Medical physics, X-ray, Quality Control, Diagnostic Radiology)

INTRODUCTION

Quality assurance in medical diagnosis is defined by the World Health Organization (WHO) as '*an organized effort by the staff operating a facility, to ensure that the diagnostic images produced by the facility are of sufficiently high quality so that they consistently provide adequate diagnostic information at the lowest possible cost and with the least possible exposure of the patient to radiation*' [1]. Quality control on the other hand is dealing with the test on a particular machine so that its performance complies with certain criteria or standards.

Since beginning of year 2000, the Ministry of Health Malaysia has imposed a requirement that every x-ray machine for medical diagnostic purpose must undergo a performance test carried out by the license class H holder. This exercise is carried out to ensure that the performance of the x-ray machine complies with the required standards set by the ministry. The standard for performance test has been set by the ministry and after performing the test the license class H holder is supposed to certify that the x-ray machine has passed the test or otherwise.

The performance test is also called quality control (QC) test. Certain QC measurement procedures for a general purpose diagnostic x-ray machine [2] has to be performed under real clinical conditions which require the use of a phantom as a substitute of a human body. This includes in testing of automatic exposure control (AEC) and in the measurement of scattered radiation [3-4]. In testing AEC the required dose [5] is set and after passing through a human body the dose is measured by a dosimetry system that will automatically stop the x-ray machine once the required dose of radiation is attained. In the measurement of scattered radiation, the amount of scattered radiation is measured at various locations after the incident x-rays are scattered by the phantom. Various types of phantom are used in diagnostic radiology for these purposes. A simple water phantom is introduced to represent an adult patient, which of course, produce interactions with radiation similar to that of a human being. The phantom is placed in the patient's position. In this paper only the scattering effect of utilizing the simplified water phantom as compared to Alderson phantom used for quality control purposes is investigated and will be presented in brief.

MATERIALS AND METHODS

X-ray machine HFQ-6000 SE, capable of producing up to 150 kV x-ray is used as a radiation source. Simple water phantoms made of perspex, dimension 30 x 30 cm square with various thickness in centimeters and filled with water is used to represent a patient. Water phantom 30 x 30 x 20 cm^3 is used to represents a normal adult patient. A child is represented by a water phantom 30 x 30 cm^2 with thickness of 5, 10 or 15 cm, whereas a thick patient is represented by 30 x 30 x 25 cm^3 water phantom. The established phantom used in this experiment is Alderson Rando Phantom (5250-0023 male therapy phantom). Radiation measurement was carried out with a Radcal 2026 C system using 180 cc chamber. Phantom to source distance is 180 cm and phantom to ionization chamber distance is 140 cm. Measurements of scattered radiation were carried out at various angles namely the angle between the perpendicular line passing through the phantom centre and radiation source and the line passing through the phantom center and the ionization chamber of Radcal 2026 C system.

Tables 1a, 1b, 2a, 2b, 3a, 3b and 4 show the results of the measurement using various units namely kilovoltage (kV), milliampere (mA), second (s) and milliampere-second (mAs). Measurement at nine positions from 10 degrees to 90 degrees at 10 degree interval, were recorded using the Radcal 2026 C system.

RESULTS AND DISCUSSION

Tables 1a, 1b, 2a, 2b, 3a, 3b and 4 indicate the strength of scattered radiation at various positions, kilovoltages and phantom thickness. The simple water phantom is chosen to replace a patient because there is no significant difference in the mass attenuation coefficients between water and tissue materials in the diagnostic x-ray energy region. Above 30 keV, the difference in the mass attenuation coefficients is within 5%. The size of the water phantom used in the set-up is 30 x 30 cm^2 with thickness 5, 10, 15, 20 and 25 cm.

Figure 1 shows that the amount of scattered radiation is gradually decreasing with increasing scattering angles. The magnitude of scattered radiation at 100 kV is about 70% higher than that at 80 kV. At a normally used technique factor (80 kV), scattered radiation was measured and found to be 13.7 uR/mAs. It is clearly seen that there is no significant differences in scattered radiation of water and of human phantom. Maximum scattered radiation is expected at 0 degree angle which include a backscattering radiation but was not measured because it does not increase the amount of scattered radiation outside the room as it is blocked by the tube housing.

Figure 2 indicates that scattered radiation increases as x-ray radiation energy increases. At 125 kV, the amount of scattered radiation is 8 times higher than that at 50 kV. However, there is no significant difference of scattered radiation, between the two phantoms at various angles.

Figure 3 represents measurement of scattered radiation caused by water phantom of varying thickness. Water phantoms of 5 to 25 cm thickness were used; 5 to 15 cm thick water phantom were used to represent a child patient, whereas water phantom of 20 cm thick was used to represent a normal adult patient and 25 cm to represent "thick" patients. It is clearly seen that the adult and thick patient phantoms produce higher scattered radiation as compared to the child phantoms. In this measurement the maximum amount of scattered radiation in thick patients at 10 degree angle is about 15.2 uR/mAs.

Results of the measurement show that a more stringent radiation safety measures should be taken when dealing with thick patients or high kV, to ensure that the radiation dose received complies with the 'as low as reasonably achievable' (ALARA) concept.

Table 1a: Scattered radiation at various angles and 80 kV x-ray using a Simple Water Phantom in quality control of general x-ray machine for diagnostic radiology

Technique Factors		Angle (degree)	Results of the measurement using Simple Water Phantom (SWP)				
			1(uR)	2(uR)	3(uR)	Average	uR/mAs
kV	80	10	38	36	37	37.00	14.80
mA	200	20	27	26	25	26.00	10.40
s	0.013	30	21	20	20	20.33	8.13
mAs	2.5	40	16	17	16	16.33	6.53
		50	13	12	12	12.33	4.93
		60	8	8	8	8.00	3.20
		70	5	5	5	5.00	2.00
		80	3	3	3	3.00	1.20
		90	2	2	1	1.67	0.67

Table 1b: Scattered radiation at various angles and 100 kV x-ray using a Simple Water Phantom in quality control of general x-ray machine for diagnostic radiology

Technique Factors		Angle (degree)	Results of the measurement using Simple Water Phantom (SWP)				
			1(uR)	2(uR)	3(uR)	Average	uR/mAs
kV	100	10	62	60	61	61.00	24.40
mA	200	20	43	42	44	43.00	17.20
s	2.5	30	34	32	32	32.67	13.07
mAs	0.013	40	27	27	28	27.33	10.93
		50	20	20	19	19.67	7.87
		60	16	16	15	15.67	6.27
		70	9	9	8	8.67	3.47
		80	7	6	7	6.67	2.67
		90	4	4	4	4.00	1.60

Table 2a: Scattered radiation at various angles and 80 kV using Alderson Rando Phantom in quality control of general x-ray machine for diagnostic radiology

Technique Factors		Angle (degree)	Results of the measurement using Alderson Rando Phantom				
			1(uR)	2(uR)	3(uR)	Average	uR/mAs
kV	80	10	34	34	35	34.33	13.73
mA	200	20	25	26	25	25.33	10.13
s	2.5	30	19	18	19	18.67	7.47
mAs	0.013	40	15	15	14	14.67	5.87
		50	12	12	11	11.67	4.67
		60	9	8	8	8.33	3.33
		70	5	6	5	5.33	2.13
		80	3	4	3	3.33	1.33
		90	2	2	2	2.00	0.80

Table 2b: Scattered radiation at various angles and 100 kV using Alderson Rando Phantom in quality control of general x-ray machine for diagnostic radiology

Technique Factors		Angle (degree)	Results of the measurement using Alderson Rando Phantom				
			1(uR)	2(uR)	3(uR)	Average	uR/mAs
kV	100	10	59	59	61	59.67	23.87
mA	200	20	44	42	42	42.67	17.07
s	2.5	30	29	29	29	29.00	11.60
mAs	0.013	40	26	26	27	26.33	10.53
		50	20	21	20	20.33	8.13
		60	15	15	16	15.33	6.13
		70	11	10	10	10.33	4.13
		80	7	7	7	7.00	2.80
		90	5	5	6	5.33	2.13

Table 3a: Scattered radiation at various kilovolts at specified angle using a Simple Water Phantom in quality control of general x-ray machine for diagnostic radiology

Parameters		kV	Results of the measurement using Simple Water Phantom (SWP)				
			1(uR)	2(uR)	3(uR)	Average	uR/mAs
Angle	10 degree	50	9	9	8	8.67	3.47
mA	200	60	15	16	16	15.67	6.27
s	2.5	70	25	26	26	25.67	10.27
mAs	0.013	80	36	37	37	36.67	14.67
		90	46	47	47	46.67	18.67
		100	57	56	56	56.33	22.53
		110	69	69	70	69.33	27.73
		120	79	79	79	79.00	31.60
		125	85	86	88	86.33	34.53

Table 3b: Scattered radiation at various kilovolts at specified angle using Alderson Rando Phantom in quality control of general x-ray machine for diagnostic radiology

Parameters		kV	Results of the measurement using Alderson Rando Phantom				
			1(uR)	2(uR)	3(uR)	Average	uR/mAs
Angle	10 degree	50	10	11	10	10.33	4.13
mA	200	60	15	16	15	15.33	6.13
s	2.5	70	28	28	27	27.67	11.07
mAs	0.013	80	35	36	36	35.67	14.27
		90	46	47	46	46.33	18.53
		100	55	55	56	55.33	22.13
		110	69	69	68	68.67	27.47
		120	82	80	79	80.33	32.13
		125	85	87	86	86.00	34.40

Table 4: Scattered radiation against Water Phantom thickness at specified angle in quality control of general x-ray machine for diagnostic radiology

Parameters		Water Phantom Thickness (cm)	Results of the measurement using Simple Water Phantom (SWP)				
			1(uR)	**2(uR)**	**3(uR)**	**Average**	**uR/mAs**
Angle	10 degree	**5**	29	29	29	29.00	11.60
mA	200	**10**	33	33	34	33.33	13.33
s	0.013	**15**	34	36	34	34.67	13.87
mAs	2.5	**20**	36	36	37	36.33	14.53
		25	38	38	38	38.00	15.20

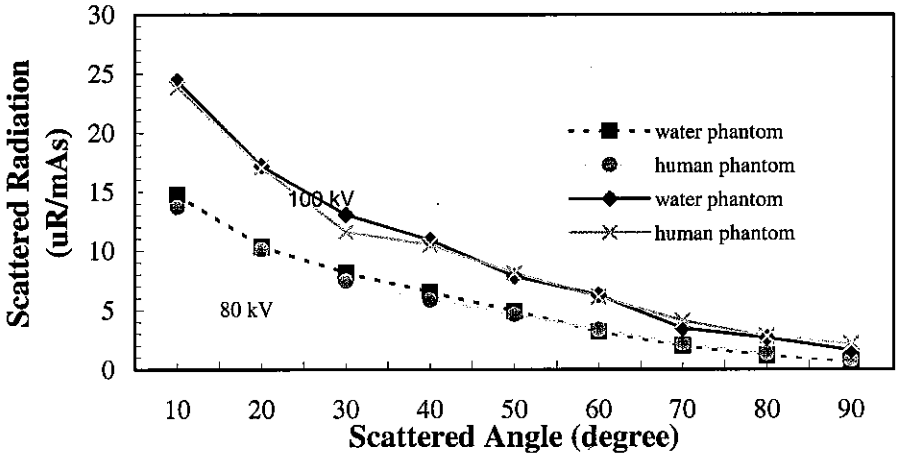

Figure 1. Variation of scattered radiation against scattering angle for a 20 cm Water Phantom and Male Alderson Phantom at 80 kV and 100 kV x-rays.

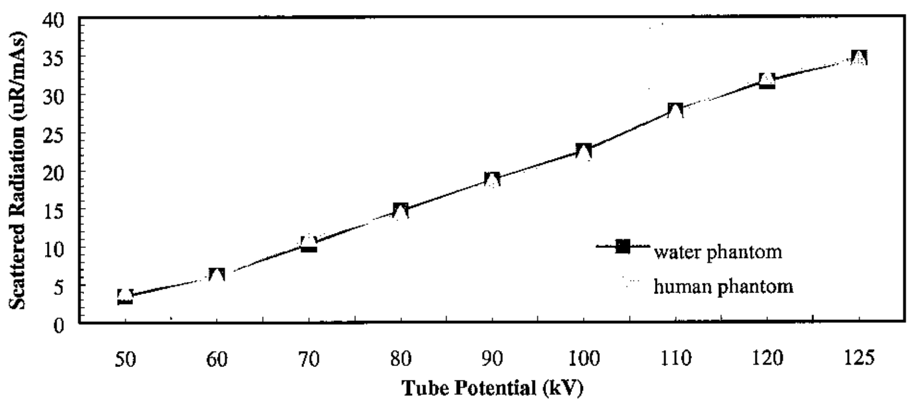

Figure 2. Variation of scattered radiation at 10° angle with tube potential in kV for 20 cm water phantom and Male Alderson Phantom.

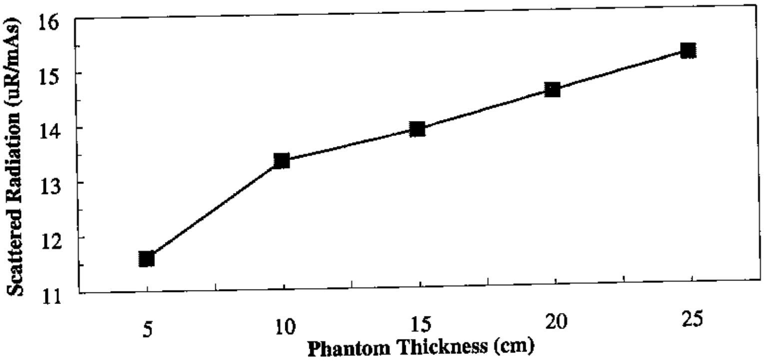

Figure 3. Variation of scattered radiation at 10° angle against Water Phantom thickness at 80 kV x-rays.

CONCLUSION

The scattering radiation from the water phantoms with various thicknesses is investigated at various locations against an established phantom normally used for quality control purpose in diagnostic radiology. From the tables and figures shown in this paper, it can be concluded that there is no any significant effect of scattering radiation at various locations if a simple water phantom is used as compared to an established phantom for diagnostic radiology.

Acknowledgement. The authors acknowledge the support given by the Malaysian Institute for Nuclear Technology Research (MINT) for providing the required facilities and staff to carry out this project and to make this paper possible.

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