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SCIENTIFIC NOTE

Variations in daily quality assurance dosimetry from device levelling, feet position and backscatter material

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Abstract Daily quality assurance procedures are an essential part of radiotherapy medical physics. Devices such as the Sun Nuclear, DQA3 are effective tools for analysis of daily dosimetry including flatness, symmetry, energy, field size and central axis radiation dose measurement. The DQA3 can be used on the treatment couch of the linear accelerator or on a dedicated table/bed for superficial and orthovoltage x-ray machines. This device is levelled using its dedicated feet. This work has shown that depending on the quantity of backscatter material behind the DQA3 device, the position of the levelling feet can affect the measured central axis dose by up to 1.8 % (250 kVp and 6 MV) and that the introduction of more backscatter material behind the DQA3 can lead to up to 7.2 % (6 MV) variations in measured central axis dose. In conditions where no backscatter material is present, dose measurements can vary up to 1 %. As such this work has highlighted the need to keep the material behind the DQA3 device constant as well as maintaining the accuracy of the feet position on the device to effectively measure the most accurate daily constancy achievable. Results have also shown that variations in symmetry and energy calculations of up to 1 % can occur if the device is not levelled appropriately. As such, we recommend the position of the levelling feet on the device be as close as possible to the device so that a constant distance is kept between the DQA3 and the treatment couch and thus minimal levelling variations also occur. We would also recommend having no extra backscattering material behind the DQA3 device during use to minimise any variations which might occur from these backscattering effects.

Keywords Radiotherapy · Quality assurance · Dosimetry · X-rays

Introduction

Radiotherapy quality assurance procedures are performed to continue the accurate delivery of radiation doses to cancer patients [1, 2]. These tasks are performed in daily, weekly, monthly and annual time periods [3]. There are various devices which can be used for such tests [4–7] including ionisation chambers, EPID’s, scintillation chambers and film. One important daily quality assurance procedure performed is the machine dose output check where a stand alone ionisation chamber or dedicated device such as the Sun Nuclear $^{+}$ (+Sun Nuclear Corporation : Melbourne, Florida 32940 USA : web: www.sunnuclear.com) DQA3 Daily QA device is used to assess radiation dose output. Of course, normally larger tolerances (e.g. 3 %) [3] are given for these values compared to a more robust fortnightly check performed in a solid water or other material phantom, however they are used to ascertain whether a secondary check at a higher level of accuracy is needed or warranted. The Daily QA device will most likely be normalised or calibrated against the secondary standard measurement and used for constancy measurements during

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the day. That is, this device should produce constant output values to serve as a dose comparison. As such, the characteristics of how it is used should remain constant. This would of course include SSD, field size used, beam energy and monitor units. Two other parameters which should be kept constant are 1. The position of the daily QA device on the treatment couch/set up area along with the amount of backscatter material behind it and 2. The positioning of the levelling feet on the device.

Whilst it may be common sense not to change the amount of backscatter material behind the QA device, sometimes the device may be placed on different parts of the treatment couch (megavoltage machines), or in the case for orthovoltage/superficial treatment (which normally do not have a dedicated treatment couch attached), may be placed in varying conditions. The second parameter mentioned, the levelling feet position becomes a more unknown factor for dosimetry in that the device is levelled daily using the 3 defined feet. With time, these feet may be adjusted higher overall, or lower overall as well as introduce a non-level position or tilt to the device. In the case of the DQA3 device the feet have 1.8 cm movement in the vertical direction and thus the device has the potential be raised this far off the couch or placed flat on the couch (if the feet are removed). This note investigates and reports on the effects on daily dosimetry of these 2 parameters.

Materials and methods

A Sun Nuclear DQA3 daily constancy checking device was used for experimental verification of the effects of feet positioning and backscatter material on measurement. This device has been described by Peng et. al. [7]. The DQA3 comprises 25 detectors, 13 parallel plate ionisation chambers and 12 diodes within a 20 cm × 20 cm field size detection area. This device is capable of measuring not only daily central axis absorbed dose response but also flatness, symmetry and photon/electron energy. Automatic temperature and pressure corrections are used and the data can be automatically recorded using the devices software database functionality. The DQA3 was tested using 2 machine types. A Varian 2100iX linear accelerator with beam energies of 6 and 10 MV x-rays and 6, 9, 12, 16, 20 MeV electrons. The Varian 2100ix machine has a carbon fibre couch for use with OBI imaging. A Gulmay d3300 was also used and produces x-ray beams of energies 50, 75, 100, 125, 150, 200 and 250 kVp. Daily QA on this machine is performed on a dedicated trolley which has a 1 cm wooden top layer that the device sits on.

As daily QA procedures involve field size, symmetry and flatness measurements, the DQA3 device is aligned and levelled on a daily basis. This is performed with the devices dedicated feet which are located in three positions on the outside edges of the device. Two are located at one end at the edges and the third in the centre of the other end of the device. This allows for easy levelling of the device on any surface required for quality assurance measurements. These feet are moved using the dedicated screw threads which allow a travel range of 1.8 cm with the feet being totally screwed down leaving the device at 0.7 cm above the table surface to fully extended and the device being 1.8 cm above the bed surface.

Testing was performed for the measured central axis dose, as well as symmetry, flatness and energy assessment (for megavoltage photons and electrons only) with this device when different feet positions are used as could be the case for normal use when the feet are used to level the device (or not). This is performed by setting up the DQA3 under a 20 × 20 cm field for all energies tested for the linear accelerator and a 10 cm diameter field size for the superficial/orthovoltage energies. The results are measured for repeated exposures of known (100 cGy) doses. Results are compared for the different feet positions as well as with the feet removed from the device. In every case, the SSD for linear accelerator measurements was adjusted to 100 cm at central axis and to either 50 cm FSD or 30 cm FSD for orthovoltage and superficial measurements respectively. Results are also collected with the device at its most non-level position, i.e. one foot completely up and the other two completely down causing the device to be tilted by 11 mm over its length to the radiation beam. This degree of tilt is very easily seen using the alignment lasers. Measurements are also performed with two different quantities of backscatter material behind the DQA3 device. In the case of the linear accelerator, irradiations are performed with the device position straight on the linac couch or with 10 cm of solid water backscatter material behind it. On the orthovoltage machine, the exposures were performed with the device having either the 1 cm wooden backing material or 10 cm of solid water backing materials for comparison. The effects of backscatter material on delivered dose are well known, however we wished to examine the effects on measure dose using the DQA3 device and the extent to which variations might occur. Results are normalised to 1 for feet position completely up to show the magnitude of variation that can occur.

All measurements were performed 5 times during each experimental session and five sessions were performed. Thus, 25 measurements were taken for each data point shown. Daily variations in LINAC output were accounted for within these measurements prior to averaging. The results shown are the average for all measurements and the percentage error shown was calculated based on one standard deviation of the mean.

Results and discussion

Table 1 shows the results for normalized dose when the DQA3 is used to measure central axis dose with no extra backscatter material positioned behind the device. That is, on the carbon fibre couch top for megavoltage x-ray and electron beams and on the 1 cm wooden topped trolley for superficial and orthovoltage x-ray beams. Results shown are for all energies used clinically at our centre. As can be seen, in this configuration, there are only minimal differences in measured dose caused by the differing feet positions on the DQA3 device. The largest difference is seen at 250 kVp with an approximately 1.6 % increase in measured dose seen from the setup of having no feet or the "off" position. This is when the device is positioned flat on the table top. At 200 kVp this value was 1.4 %. At all other energies and feet positions results are within 1 %. One point to notice in Table 1 is that all results increase in normalized dose as the device gets closer to the treatment couch, except for 6 MV x-rays. This anomaly produces up to 0.4 % reduction in measured dose with decreasing air gap between the DQA3 and the treatment couch. Comparatively, the 10 MV beams produce a negligible 0.1 % variation. We believe that this anomaly in results in not related to any physical phenomena but caused by uncertainty in measurements with the normalized feet extended result having a 0.4 % (1SD) uncertainty. Measurements were also made for variations in symmetry, flatness and beam energy in these different feet positions or heights. No significant effects were measured with negligible variations for symmetry and flatness and variations up to 0.3 % seen for energy calculation. Measurements were also made on different parts of the linear accelerator treatment couch however no significant differences were seen in measurements. This may not be the case for older style treatment couches where metal support bars are located in the couch if the device is positioned above then.

Table 2 however shows results when backscatter material is placed behind the DQA3 (10 cm solid water), which may be the case for some clinical setups, or situations using the DQA3. Here results show a larger variation in measured dose with feet position. Up to approximately 1.8 % (250 kVp) variation in measured central axis dose is seen with energies 150 kVp through to 10 MV recording at least 1.3 % variation. Electrons remain relatively unaffected however superficial energies (50 to 150 kVp) record some effects as well (0.3 to 1.1 %). These effects can be attributed to a change in ratio of back scatter radiation dose contribution delivered to the DQA3 device from the extra material placed behind it. These values are of course energy specific and will be defined not only by the backscatter/peak scatter factors for the beams in question but also by the intrinsic absorption of radiation in the back side metal casing of the DQA3 device. At 250 kVp, the change in central axis dose between the two extreme positions varied from 1.6 (no extra backscatter) to 1.8 % with 10 cm extra solid water backscatter. This is not a significant change and shows that at this energy, the extra backscatter did not significantly affect measured dose. However at other energies the change is larger.

Of course, a situation might also occur where the user of the DQA3 might have been unaware of the conditions of calibration in terms of set up and backscatter material. That is, with or without a presence of backscatter material or variation in quantity of backscatter. In this case, Table 3 shows the variations that occur in measured central axis dose for 2 configurations. Results are normalized (or calibrated) to 1 for "no backscatter material present".

In these cases a much larger effect occurs whereby up to 7.2 % variation in measured dose occurs (6 MV x-rays). Interestingly the lower energy x-ray beams from 50 kVp up to 125 kVp are relatively unaffected in this situation (maximum 1.2 % variation). These energy beams still have large backscatter factors, (1.19–1.25) [8] however the contributions to dose must be localized to within the DQA3 device itself. Once these energies are exceeded the level of variation increases. Also of note is that electron beams only produce a maximum variation of 1.1 % for carbon fibre couch top versus 10 cm solid water backscatter material. Thus producing a minimal effect.

Results were also measured for the effect of the device being positioned unevenly on the treatment couch and thus not leveled. Table 4 shows results for the variation in measured dose, symmetry (radial), flatness (radial) and energy when the device was either 5.5 mm higher on one side compared to the other (half tilt) or 11 mm (full tilt) for selected megavoltage x-ray and electron beams. The tilt was along the radial direction.

As can be seen there was a minimal impact on dose variations with a maximum of 0.1 % for electrons and 0.3 % for x-rays. Similar effects are seen for flatness with less than 0.2 % variation measured. However the tilt did have an impact on measured symmetry with variations of up to 1 % seen for both electrons and x-rays and similar magnitude variations seen in calculated energy (up to 1.1 %). The degree of tilt which caused these variations was significant and would normally not go unnoticed when set up of the device was performed. However, it shows that the device should be leveled (at least approximately) during measurement. This can be most easily achieved in conjunction with providing the most reproducible DQA3/couch distance by screwing the feet of the device completely down to make the DQA3 as close as possible to the treatment couch during use. Similar measurements were not performed with kVp beams as this is not clinically relevant as the kVp cones are placed directly on the DQA3

Table 1 Normalised central axis dose: no extra backscatter material

	Feet position					
	Extended (1.8 cm gap)		Closed (0.7 cm gap)		Off (0 cm gap)	
	Value	Uncertainty (St Dev) (%)	Value	Uncertainty (St Dev) (%)	Value	Uncertainty (St Dev) (%)
X-rays						
50 kVp	1.000	0.3	1.003	0.3	1.003	0.3
75 kVp	1.000	0.1	1.000	0.1	1.002	0.2
100 kVp	1.000	0.3	1.000	0.1	1.004	0.1
125 kVp	1.000	0.1	1.001	0.1	1.005	0.1
150 kVp	1.000	0.1	1.001	0.1	1.008	0.2
200 kVp	1.000	0.1	1.006	0.1	1.014	0.1
250 kVp	1.000	0.3	1.009	0.1	1.016	0.1
6 MV	1.000	0.4	0.996	0.1	0.997	0.2
10 MV	1.000	0.1	0.999	0.2	1.000	0.1
Electrons						
6 MeV	1.000	0.1	1.000	0.1	1.000	0.1
9 MeV	1.000	0.2	0.996	0.3	0.996	0.4
12 MeV	1.000	0.1	0.998	0.2	0.996	0.2
16 MeV	1.000	0.2	0.999	0.2	0.998	0.2
20 MeV	1.000	0.2	0.998	0.2	0.996	0.3

Table 2 Normalised central axis dose: 10 cm solid water backscatter material

	Feet position					
	Extended (1.8 cm gap)		Closed (0.7 cm gap)		Off (0 cm gap)	
	Value	Uncertainty (St Dev) (%)	Value	Uncertainty (St Dev) (%)	Value	Uncertainty (St Dev) (%)
X-rays						
50 kVp	1.000	0.2	1.004	0.1	1.004	0.2
75 kVp	1.000	0.1	1.003	0.2	1.003	0.2
100 kVp	1.000	0.1	1.006	0.1	1.008	0.2
125 kVp	1.000	0.1	1.006	0.2	1.011	0.2
150 kVp	1.000	0.1	1.009	0.1	1.016	0.5
200 kVp	1.000	0.2	1.012	0.1	1.015	0.3
250 kVp	1.000	0.1	1.016	0.1	1.018	0.2
6 MV	1.000	0.2	1.007	0.2	1.018	0.1
10 MV	1.000	0.1	1.006	0.2	1.013	0.3
Electrons						
6 MeV	1.000	0.1	1.001	0.2	1.001	0.1
9 MeV	1.000	0.2	0.999	0.1	0.998	0.1
12 MeV	1.000	0.1	0.998	0.1	0.997	0.1
16 MeV	1.000	0.2	1.002	0.2	1.003	0.2
20 MeV	1.000	0.1	1.002	0.2	1.003	0.2

device during measurement and a tilt of the beam compared to the DQA3 device should never occur.

These results highlight that the DQA3 device is a relatively accurate and reproducible daily constancy checking device for central axis radiation dose and that the material placed behind the device can significantly affect results, especially at x-ray energies from 150 kVp to 10 MV. Results have also highlighted that variations up to 1.8 % can be caused by the feet position alone when backscatter material is used behind the DQA3 device during

Table 3 Variation in central axis measured dose with 10 cm solid water backscatter added. (Calibrated with no backscatter material present)

	Feet position		
	Extended (1.8 cm gap) Value	Closed (0.7 cm gap) Value	Off (0 cm gap) Value
X-rays			
50 kVp	0.992	0.993	0.994
75 kVp	0.999	1.002	1.000
100 kVp	1.001	1.008	1.005
125 kVp	1.007	1.012	1.012
150 kVp	1.012	1.021	1.021
200 kVp	1.041	1.048	1.042
250 kVp	1.050	1.058	1.052
6 MV	1.051	1.063	1.073
10 MV	1.034	1.041	1.048
Electrons			
6 MeV	1.002	1.003	1.004
9 MeV	1.002	1.005	1.005
12 MeV	1.005	1.005	1.006
16 MeV	1.003	1.005	1.008
20 MeV	1.004	1.008	1.011

Table 4 Effects of device "tilt" or non levelling on measurement parameters compared to no tilt

Beam energy	Tilt (mm)	Dose	(%Difference)		
			Symmetry	Flatness	Energy
6 MV	5.5	0.3	0.4	0.1	0.5
6 MV	11	0.3	0.8	0.2	1.1
10 MV	5.5	0.1	0.4	0.0	0.4
10 MV	11	0.1	0.6	0.1	0.8
6 MeV	5.5	0.1	0.2	0.0	0.2
6 MeV	11	0.1	0.5	0.1	0.2
12 MeV	5.5	0.1	0.3	0.1	0.1
12 MeV	11	0.1	0.7	0.1	0.1
20 MeV	5.5	0.1	0.5	0.1	0.1
20 MeV	11	0.1	1.0	0.2	0.1

irradiation. Whilst these values are not large, they are significant enough to consider and show that the DQA3 feet should be kept at a defined position to improve and keep accuracy. A position as close as possible to the DQA3 would be recommended so that the device is approximately level and has the same backscatter conditions as was used for device calibration all the time. The DQA3 device should also be used with a minimal amount of backscatter material behind it.

The DQA3 should of course only be irradiated in the same scattering conditions as well, which is relatively well known, however this worked has highlighted that up to 7.2 % variation in measured central axis dose can occur if this aspect of daily QA is not kept constant.

Conclusion

A 7.2 % variation in measured daily central axis dose was measured with the DQA3 device, caused by 10 cm of solid water backscatter material placed behind it during irradiation. This was found for 6 MV x-rays. Other energy beams also recorded significant changes in measured dose with 10 cm of backscatter material added. The positioning of the feet height on the device also affects dose measurement by up to 1.8 %. As such the device should be used with as little backscatter material behind it as possible and we recommend that the feet position be screwed in completely to not only provide reproducible DQA3 to couch distance but to also provide at least an approximate level for the device during use. A larger tilt of the device or non-level position can affect symmetry and energy measurement by up to 1 %.

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