Available online at www.sciencedirect.com

ScienceDirect

journal homepage: http://www.elsevier.com/locate/rpor

Original research article

Sensitivity of the IQM and MatriXX detectors in megavolt photon beams

*Oluwaseyi Michael Oderinde**, *Freek du Plessis*

Department of Medical Physics, University of the Free State, PO Box 339, Bloemfontein 9300, South Africa

ARTICLE INFO

Article history:
Received 18 January 2019
Received in revised form
12 June 2019
Accepted 11 July 2019
Available online 2 August 2019

Keywords:
Sensitivity
Quality assurance
IQM detector
MatriXX detector

ABSTRACT

Aim: This study focused on evaluating the sensitivity of integral quality monitoring (IQM®) system and MatriXX detectors. These two detectors are recommended for radiotherapy pre-treatment quality assurance (QA).

Background: IQM is a large wedged-shaped ionisation chamber mounted to the linear accelerator (linac) head in practice. MatriXX consists of an array of ionisation chambers also attached to the linac head.

Materials and methods: In this study, the dosimetric performance and sensitivity of MatriXX and IQM detectors were evaluated using the following characteristics: reproducibility, linearity, error detection capability and three-dimensional conformal radiotherapy (3D-CRT) plans of the head and neck, thorax and pelvic regions.

Results: This study indicates that the signal responses of the large ionisation chamber device (IQM) and the small pixel array of ionisation chambers device (MatriXX) are reproducible, linear and sensitive to MLC positional errors, backup jaw positional errors and dose errors. The local percentage differences for dose errors of 1%, 2%, and 3% were, respectively, within 0.35–8.23%, 0.78–16.21%, and 1.10–24.41% for the IQM device. While for the MatriXX detector, the ranges were between 0.24–3.19, 0.57–6.43 and 0.81–12.95, respectively. Since IQM is essentially a double wedge-shaped large ionisation chamber, its reproducibility and detection capability are competitive to that of MatriXX. In addition, the sensitivity of the two QA systems increases with an increase in escalation percentage, and the signal responses are patient plan specific.

Conclusions: The two detectors response signals have good correlations and they are accurate for pre-treatment QA. Statistically, ($P < 0.05$) there is a significant difference between the IQM and MatriXX response to dose errors.

1. Background

The evolution of conformal treatment techniques, such as intensity modulated radiotherapy (IMRT), has optimised radiation treatment by delivering an effective dose to a tumour while sparing normal tissue.[1,2] However, it is a norm to verify this advanced RT technique, which has accompanied complexities in their pre-treatment quality assurance (QA).[3,4] Two-dimensional (2D) detector arrays are now more useful than film measurements during radiotherapy verification due to their fast, automated readout with high efficiency.[5–9]

* *Corresponding author.*
E-mail addresses: 2014186577@ufs4life.ac.za, oderindeseyi02@gmail.com (O.M. Oderinde), duplessisfcp@ufs.ac.za (F. du Plessis).
https://doi.org/10.1016/j.rpor.2019.07.007

IQM[10,11] MatriXX[12,13] are two of such detectors available at our clinic for pre-treatment QA procedures.

Several studies have evaluated the sensitivity of IQM and MatriXX devices separately by altering the multi-leaf collimator (MLC) positions, but none has evaluated the QA systems in terms of dose-variation errors.[14–16] Some articles, such as Chung et al., evaluated the signal-response of a MatriXX detector, Gafchromic EBT film, and MapCHECK device using patient-specific treatment plans.[3] Also, Li et al. compared the dose response of open fields using MatriXX and MapCHECK detectors.[14] While Deshpande compared the sensitivity response of MatriXX and ArcCHECK to systematic offsets of backup Jaws and open MLC positions of head and neck treatment plans.[17] Elsewhere, Oderinde and Du Plessis evaluated the sensitivity of IQM to MLC positional error using Monte Carlo simulation while Saito et al. studied the IQM response to MLC positional errors of patients' plans.[18,19]

2. Aim

In this study, IQM and the MatriXX detectors were initially evaluated based on their responses (performance) to dose-rates, monitor units (MUs), photon energy beams, and minimal alterations of jaws and multi-leaf collimators (MLCs) of considered segments. Then, the sensitivity of the two commercial QA systems was evaluated by modifying the three-dimensional conformal radiotherapy (3D-CRT) patients' planning target volume (PTV) dose at 1%, 2%, and 3%.

3. Materials and methods

3.1. *IQM and MatriXX QA detectors*

The commercially available IQM (iRT Systems GmbH, Koblenz, Germany) was prototyped by Islam et al.[10] It is a double wedge-shaped open ionisation chamber with a large volume. Its polarising 1.5 mm aluminium electrode plates are angled relative to the central electrode along the multileaf collimator (MLC). The double wedged ionisation chamber has a sensitive area of $26 \times 26\ cm^2$ which makes it suitable for $40 \times 40\ cm^2$ field measurement at the isocenter. The electronic signal (numeric values) of IQM is a function of the photon fluence distributed on the surface of the detector's plate which is of the order of nC (nano Coulomb). Previous articles have discussed explicitly the design, setup, calibration, and considerable factors of the IQM system.[16,10,20]

MatriXX (IBA Dosimetry, Scanditronix Wellhofer GmbH, Germany) is a 2-dimensional (2D) array of 1020 vented ionisation chambers arranged in a 32×32 matrix. Each chamber has a sensitive volume of 0.08 cc, a diameter of 4.5 mm, and height of 5 mm. The spacing between the two chambers measured from their centres is 7.62 mm. The active point of measurement is 3.6 mm from its surface. It operates at a potential of 500 V and has a sensitive area of $24 \times 24\ cm^2$.[13,21] A MatriXX detector can be mounted on a linac head to have 90% of the irradiated beam on the surface of the detector or positioned at isocentre when in use.

3.2. *IQM and MatriXX measurement*

IQM was mounted to the linac head, as shown in Fig. 1a, and its readout signals were transferred through the dosimetry controller to the IQM manager (computer) either for initial recording or for verification of patient's plans. It measures the photon beam output as it traverses the chamber volume and reports a signal to the computer. The checksum function of the IQM system permits the recording of each signal for every beam and segment during measurement. IQM has no chamber warm-up time and the signal has no unit.

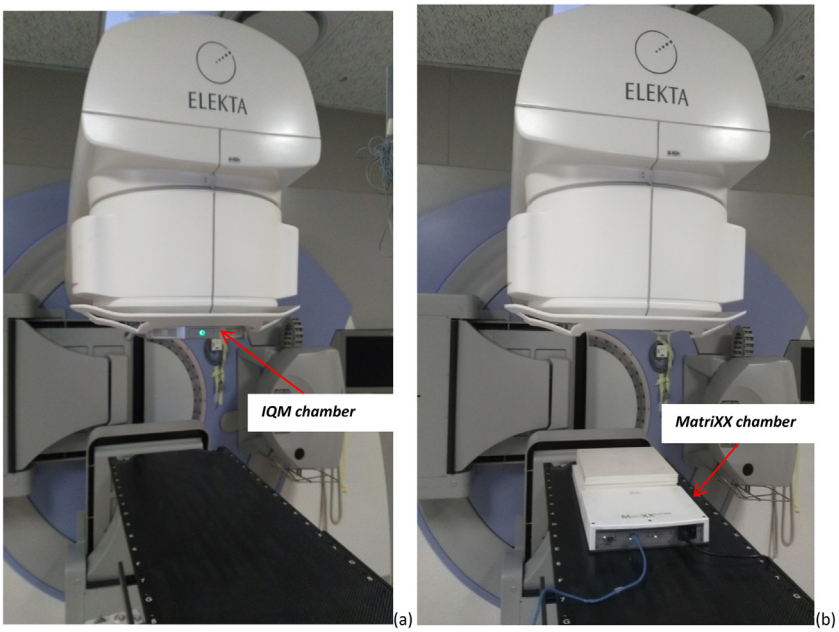

Fig. 1 – Linac setup with (a) IQM detector mounted on the head (b) MatriXX detector placed on the couch with 5 cm Perspex plate on top of the array.

The MatriXX device underwent a 15-min pre-measurement warm-up time as recommended by the manufacturers. The measurements of MatriXX were obtained using the OmniPro-I'mRT v.1.7 software (IBA dosimetry GmbH, Germany). In this study, the measurements were obtained from the four central chambers of the 2D array positioned at 100 cm source-to-detector distance (SDD) as utilised in related articles.[3,12,14] MATLAB code (Mathwork, Inc., Natick, MA) was used to automatically generate an average absolute signal (mGy) for each of the four chambers from the exported ASCII format files from the OmniPro-I'mRT software. Using manufacturers' specified values, a 5 cm thick Perspex-slab was placed on the MatriXX detector as shown in Fig. 1b.

3.3. *Ionisation measurement*

All measurements were performed on an Elekta Synergy linac (Elekta instrument AB Stockholm, Sweden). The linac operates at 6, 10 and 15 MV photon beams and is equipped with a low transmission (<0.5%) Agility head of 160 interdigitating leaves (width = 0.5 cm at isocenter). The linac output consistency was verified with a PTW farmer chamber (sensitive volume of 0.6 cm^3). The consistency of the ionisation chamber was verified using a radioactive Sr-90 check source. The PTW signals were corrected by standard environmental conditions (pressure and temperature) of the clinic. The temperature of the PTW farmer chamber was measured in the check source, as was the pressure. Afterwards, the calculated values of the environmental conditions were multiplied by the ionisation chamber readings.

The radioactive check source signal was consistent after 30 minutes' warm-up of the PTW UNIDOS® E Universal electrometer. The ionisation chamber was inserted to the depth of 5 cm depth a Perspex phantom to verify the linac consistency at 100 cm SSD. The coefficient of variation of the Elekta Synergy equipped with Agility 160-MLC leaves linac setup was within 0.06% (48.15 ± 0.03) when verified with a PTW farmer chamber for 3 × 3 and 10 × 10 cm^2 fields. This chamber and electrometer were also used to measure the dose linearity and dose-rate dependence of the linac between 10 and 600 MU and 50 (1 MU = 1 cGy for 10 × 10 cm^2 fields at 100 cm SSD), and 800 MU/min at 300 MU dose rate setting, respectively. Also, the beam quality was set to 6 MV at zero degree for both the gantry and collimator angle.

3.4. *Performance tests*

3.4.1. *Reproducibility*

The signal response of the IQM and MatriXX detectors was calibrated, and their reproducibility was tested over a usage period of three months, whereby, the QA systems were irradiated by open fields of 3 × 3 and 10 × 10 cm^2 at 6 MV for 300 MU. The weekly measurements were repeated ten times in a batch to calculate the coefficient of variation (CV) for each week. Variation should be approximately zero (CV ≈ 0%) to avoid inherent uncertainties from the linac that could skew the detector's response signal.

3.4.2. *Dose linearity and dose rate dependence*

For dose linearity and dose-rate dependence, the detectors were exposed to an open field of 10 × 10 cm^2 at 6 MV. The dose linearity of the detectors was tested by measuring their signals between 10 and 600 MU five times. The open field signals for dose rates between 50 and 800 MU/min at a fixed monitor unit (300 MU) set on the console were recorded over five readings for both detectors.

3.4.3. *Photon energy beam dependence*

For the photon beam dependence test, the response of each detector was investigated as a function of field sizes for 6, 10 and 15 MV photon beams at 300 MU. Open field sizes ranging from 3 × 3 to 20 × 20 cm^2 were measured five times, while 10 × 10 cm^2 field was set as the baseline measurement for each photon beam.

3.4.4. *Error detection capability*

To evaluate the sensitivity of the IQM and MatriXX detectors, 3 × 3 and 10 × 10 cm^2 fields were utilised. The signals for the two segments were measured with and without alterations. The altered segments were defined by systematic offset of the; (a) jaw positions within ±0.5, ±1 and ±2 mm and (b) MLC opened leaf positions within ±0.5, ±1 and ±2 mm as graphically shown in Fig. 2 for a 10 × 10 cm^2 field. To evaluate the error detection capability, chamber readings were quantified using a percentage change (P_c) with reference to the unaltered readings as calculated in Eq. (1) . In this equation, R_{err} and

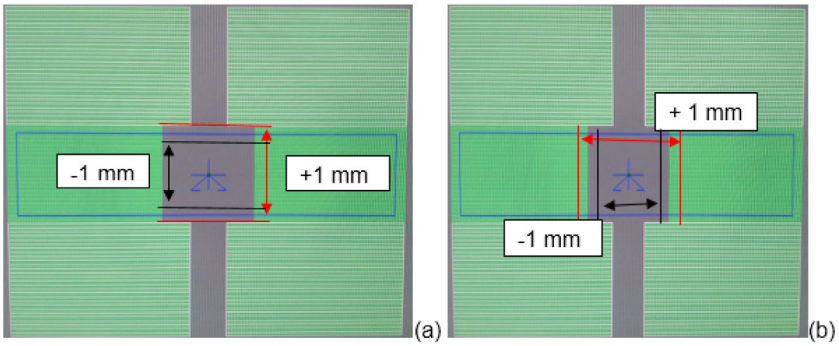

Fig. 2 – Definition of field errors: (a) diaphragm modification within ±1 mm; (b) MLC modification within ±1 mm for 10 × 10 cm^2 field.

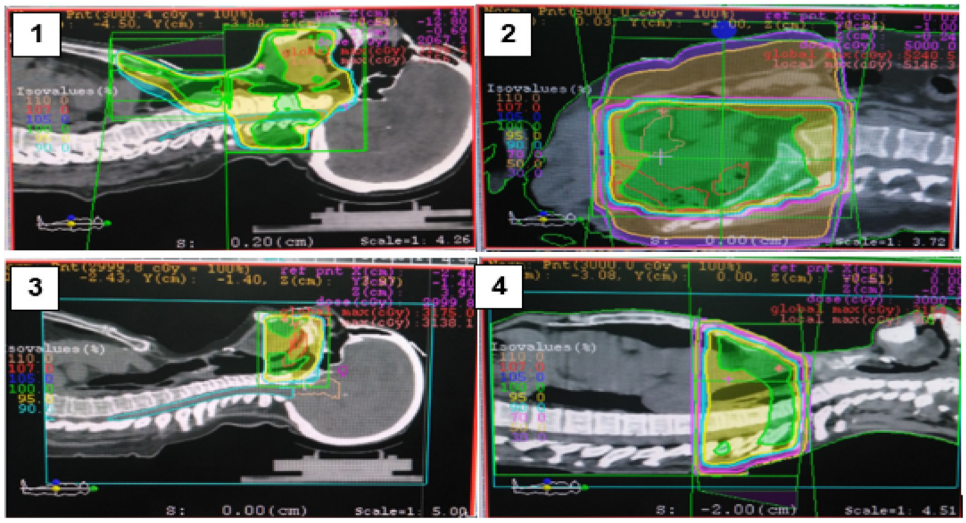

Fig. 3 – Patients treatment plans used in this study (1 and 3 head and neck), (4 thorax), and (2 pelvis).

R_{ref} are the chamber readings of the altered segment and the unaltered segment, respectively.

$$Pc\,(\%) = \left(\frac{R_{err} - R_{ref}}{R_{ref}}\right) \times 100 \quad (1)$$

The quantified P_cs were correlated with the segment errors for both the IQM and MatriXX data using Pearson correlation coefficient (R^2). The Mann–Whitney test was used to compare the IQM with MatriXX correlations for jaws and MLC offsets at 3×3 and $10 \times 10\,cm^2$ fields. A P-value ($P < 0.05$) is considered as a statistically significant difference between the two detector response signals.

Error detection capability for both ionisation chambers was analysed for the cases of 3D-CRT treatment plans (Head and Neck, Thorax, and Pelvis plans). The patient plans were executed using Elekta's XiO® planning system; afterwards, the plans were transferred to MOSAIQ Radiation Oncology information system. Fig. 3 shows examples of the treatment plans used in this study. The prescribed doses in Table 1 were escalated by 1%, 2% and 3% for fixed patient treatment plans. To measure the altered beam output, the IQM device was mounted to the linac head surface while the MatriXX detector was attached to the gantry using the gantry holder. The Mann–Whitney test was used to compare the IQM with MatriXX response signals for the altered plans.

4. Results

In this study, the sensitivity of two different detectors was investigated. We initially evaluated the dosimetric performance of the two QA systems using the following characteristics: dosimetric reproducibility, dose linearity, dose rate, and photon dependence.

Fig. 4 shows the dose and dose-rate dependence for the linac using the PTW Farmer ionisation chamber for 10–600 MU and 50–800 MU/min, respectively, at 6 MV. The correlation coefficient for the linear fit on dose dependence was $R^2 = 1$. The PTW response was linear over the range of MU considered. For dose-rate dependence, the ionisation chamber response was normalised at 300 MU/min, and it shows an independent correlation with an increase in dose-rate values. The first test was performed to verify the accuracy of the accelerator beam output as a function of increasing MUs. The second test verified that the beam output of the linear accelerator was independent of the dose rate at which the dose was delivered. It was important to verify that at first to evaluate the linear accelerator stability regarding beam output as scaled by monitor units and, additionally, delivering a constant output at different

Table 1 – Patient's treatment plan parameters used for this study.

Treatment site	Field #no	Precribed dose (cGy)	MU	Beam quality (MV)	Gantry (°)	Collimator (°)	Field size (cm^2)
H&N1	F1	40.00	175.70	15.00	75.00	270.00	14.5 × 8.5
	F2	44.00	189.50	15.00	285.00	90.00	14.5 × 8.5
Thorax	F1	86.00	109.40	6.00	90.00	0.00	14.4 × 14.5
	F2	86.00	111.00	6.00	270.00	0.00	14.4 × 14.5
	F3	86.00	170.30	6.00	0.00	180.00	25.2 × 8.0
Pelvis	F1	143.00	167.60	6.00	0.00	0.00	23.7 × 26.5
	F2	143.00	162.40	6.00	180.00	0.00	22.5 × 26.5
	F3	15.00	20.70	15.00	90.00	0.00	9.9 × 23.4
H&N2	F1	8.00	8.20	15.00	90.00	0.00	12.4 × 15.9
	F2	8.00	9.50	6.00	270.00	90.00	11.3 × 12.0

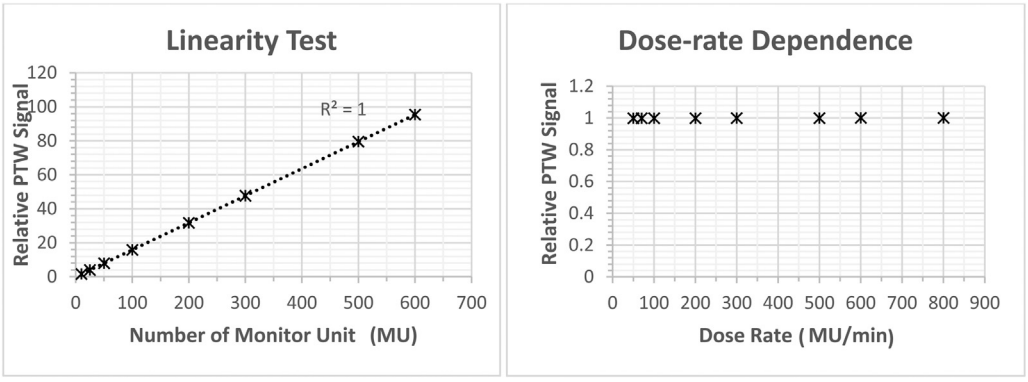

Fig. 4 – The signal of PTW farmer ionisation chamber for (a) dose linearity and (b) dose-rates at 6 MV photon beams.

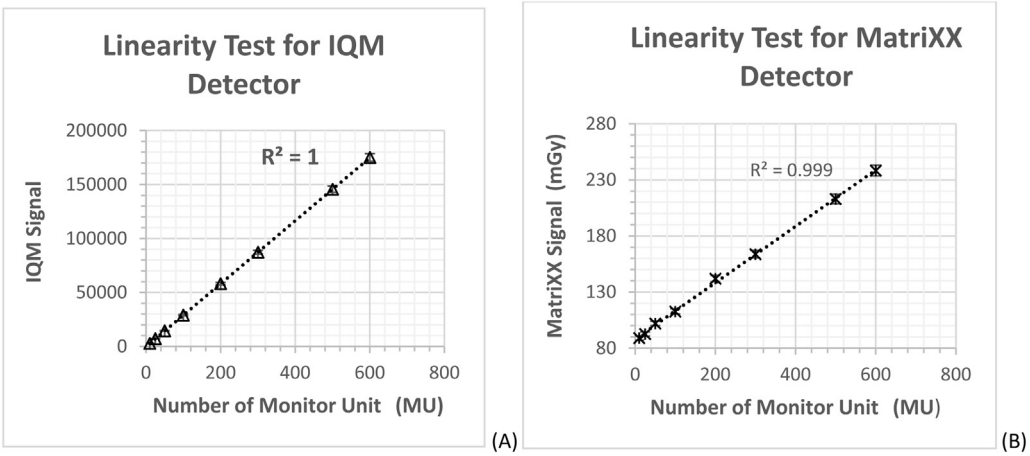

Fig. 5 – Linearity test for the two detectors and uncertainties. The reading is plotted as a function of MU from 25 to 600 MU for 6 MV photon beams (A) for IQM detector and (B) for MatriXX detector.

dose rates. These tests show that the linear accelerator is very stable in terms of linearity and dose rate since the beam output for the three-month period fluctuated within 0.06%.

4.1. *Reproducibility*

Table 2 shows the CVs (Mean ± Standard Deviation) for the IQM output signal and the average value of the four central pixels output signal of the MatriXX ionisation chamber response when tested for three months. The measurements were repeated 10 times in a batch for each month. The CVs were calculated for each batch per month for the two commercial detectors considered.

The two detectors are reproducible over the period tested for fixed field sizes over three months. CVs for the IQM signals range between 0.07% and 0.11% and the MatriXX signal ranges from 0.75% to 1.08%. The CVs show that the IQM signals are more consistent when compared with the MatriXX signals for 3×3 and $10 \times 10\,cm^2$ field sizes considering 6 MV photon beams. A slight inconsistent response in the MatriXX signal will generate a higher CV compared to the IQM signal. This is an expected fact since the IQM is a large ionisation chamber compared to the central four 0.08 cc ionisation chambers of MatriXX. The MatriXX detector could have intrinsic discrepancies up to 4%.[22] However, the CVs of MatriXX are within the acceptable limits of ±3% according to the IEC 61674 standard.[23]

4.2. *Dose linearity and dose-rate dependence*

The results of the linearity tests are shown in Fig. 5. Both IQM and the four central pixels of the MatriXX reading showed linearity with MU. The IQM and MatriXX signals increase with an increase in MU. The correlation coefficients show that the linear relationship between the MU and the 2D array ionisation chamber response is good, with the IQM and MatriXX devices having coefficients of 1.00 and 0.99, respectively. The detectors' response signals were definitely influenced by the inherent uncertainties of individual detectors accompanied by systematic uncertainties from the beam output. Influence of uncertainties in the IQM and MatriXX signal responses are within 1% and 3%, respectively. Fig. 6 presents the dose-rate dependence test for the two detectors and uncertainties. The reading is plotted as a function of MU/Min from 50 to 800 MU/min considering 6 MV photon beams. It is observed that IQM and MatriXX detectors' signals are independent of the dose rates considered.

Table 2 – The coefficient of variations (Mean ± Standard Deviation) for the IQM detector, MatriXX detector, linac, and PTW pinpoint ionisation chamber response over three months.

Detector	Month 1		Month 2		Month 3	
Field size	$3 \times 3\,cm^2$	$10 \times 10\,cm^2$	$3 \times 3\,cm^2$	$10 \times 10\,cm^2$	$3 \times 3\,cm^2$	$10 \times 10\,cm^2$
IQM	0.10% (87,452.86 ± 91.23)	0.07% (805,829.92 ± 585.13)	0.09% (87,030.62 ± 86.24)	0.07% (806,811.53 ± 594.13)	0.11% (86,937.86 ± 91.51)	0.08% (817,811.50 ± 650.22)
MatriXX (mGy)	1.08% (137.21 ± 1.48)	1.06% (155.89 ± 1.66)	0.90% (139.05 ± 1.26)	0.75% (156.42 ± 1.12)	0.91% (138.45 ± 1.17)	0.85% (157.69 ± 1.34)
Linac (nC)	0.06% (42.19 ± 0.02)	0.06% (48.15 ± 0.03)	0.06% (42.44 ± 0.03)	0.06% (48.15 ± 0.03)	0.06% (42.19 ± 0.02)	0.05% (48.11 ± 0.03)
PTW (nC)	0.041% (1.2013 ± 0.0005)		0.041% (1.1999 ± 0.0005)		0.041% (1.1923 ± 0.0005)	
PTW temp. (°C)	22		22		21.5	
PTW pressure (hPa)	859		860		857	

According to AAPM reports, it is recommended that an ion chamber detector is used for MU checks, which is a standard practice to verify advanced RT plans.[24] In this study, the detectors' linearity was considered for convectional MUs, and it showed that the IQM and MatriXX detectors are independent of dose-rate ≤800 MU/min.

4.3. *Photon energy beam dependence*

Fig. 7 presents the beam energy dependence of the IQM and the MatriXX chamber devices according to the square field areas varying from 3×3 to $20 \times 20\,cm^2$ for 6, 10 and 15 MV photon beams. An increase in photon energy beam causes an increase in signal responses. Both large (IQM) and small array (MatriXX) ionisation chamber devices do not have the same energy response curves over the field sizes investigated. The IQM signal response to field sizes shows a similar response curves as those produced in related articles.[11,16,20] The PTW ionisation chamber and MatriXX response signals increase with an increase in field sizes. MatriXX uses the four central detectors, and the signal is equivalent to the familiar beam output trend for an ionisation chamber measurement in a large phantom. At large fields, the signals in the four central chambers will reach a saturation value since the scattering signals will not contribute much more at larger fields. Secondary electrons reaching the ionisation chambers will have a limited range, mainly at a larger energy.

The IQM signal shows an increase that is higher at an increased field size. Effect of energy fluence and contaminant electron at large field for a high photon beam is pronounced in the IQM response signal. This effect causes significant variations in output signal at large fields of different incident beams. Furthermore, not only an increased scattering from the radiation head accounts for the higher signal but also the fact that IQM has a wedge shape; therefore, relatively more ionisation events take place in its sensitive volume contributing to increased signals.

In addition, calibration of the detector plays an integral role in the beam output signals. Since the calibration factors were supplied by the manufacturers, users can demand for re-calibration of the device to suit dose distribution in a water phantom/Monte Carlo calculation which is the gold standard for clinical dosimetry. It is advisable for users to calibrate the detectors response signals and compare them with their water phantom measurements, and validate the calibration factors over time, which is in line with Annual QA procedures.[24] However, the IQM output signals show a similar output curve to the water phantom measurements and Monte Carlo simulations in AAPM TG 74 report.[25]

4.4. *Error detection capability*

Fig. 8 shows the error detection capability of IQM and MatriXX for systematic errors of ±0.5, ±1 and ±2 mm in the back-up diaphragm (jaw) and MLC settings of the Elekta Synergy linac. In Fig. 8a, the percentage change in the IQM signal to jaw modification for 3×3 and $10 \times 10\,cm^2$ fields ranges between 0.62–9.58% and 0.05– 3.84%, respectively, while the percentage change in the MatriXX signals for the two fields considered was within 0.11–4.62% for $3 \times 3\,cm^2$ and 0.03–1.35%

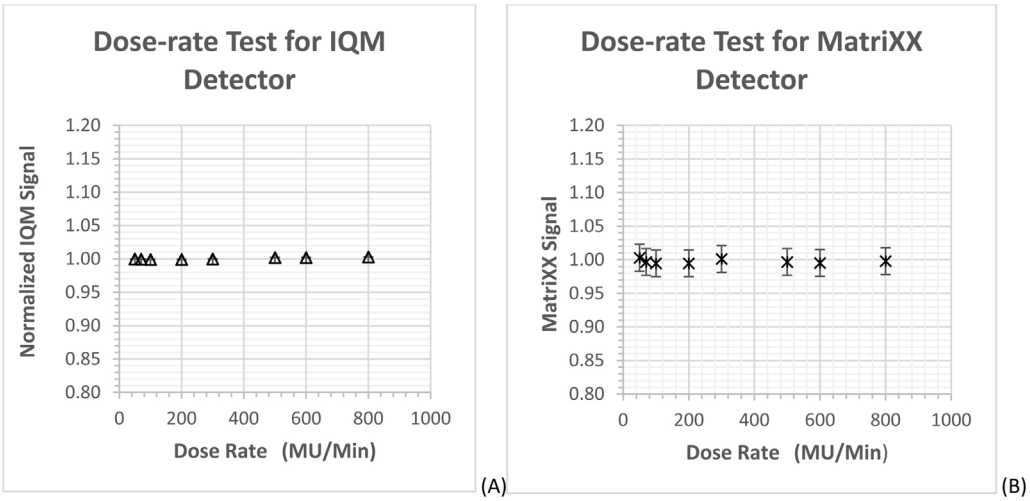

Fig. 6 – Dose-rate dependence test for the two detectors and uncertainties. The reading is plotted as a function of MU/min from 50 to 800 MU/min considering 6 MV photon beams (A) for IQM detector and (B) for MatriXX detector.

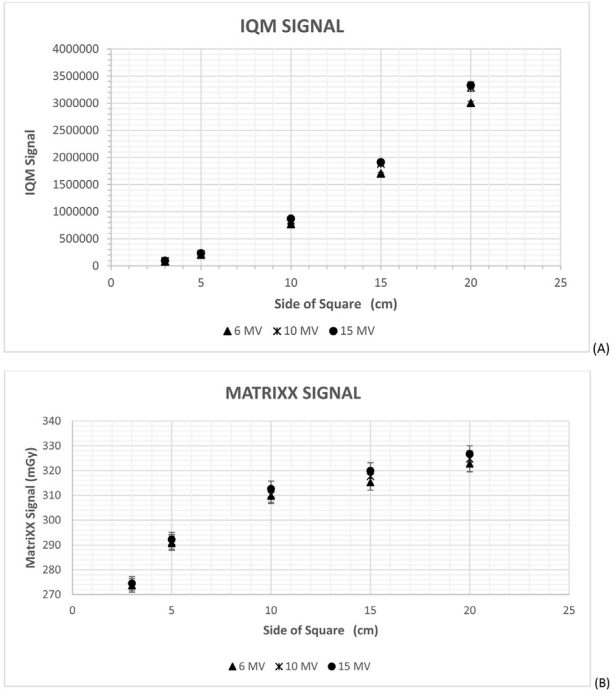

Fig. 7 – Output signals for the two detectors with their uncertainties. The reading is plotted as a function of the side of a square field from 3 to 20 cm at 6, 10 and 15 MV photon beams (A) for IQM detector and (B) for MatriXX detector.

for $10 \times 10\,cm^2$ field. Fig. 8b shows the percentage change in the IQM and MatriXX signal for modifications of MLC to 3×3 and $10 \times 10\,cm^2$ fields which ranges between 1.48–8.67% and 0.61–4.44% for the IQM signals and 0.37–4.74% and 0.23–1.55% for the alteration in the MatriXX signals.

Table 3 shows the correlation coefficients and *P*-values (for the jaws and MLC errors at 3×3 and $10 \times 10\,cm^2$ fields. The IQM and MatriXX response signals show significant correlations ($R^2 > 0.95$) with the systematic errors for the segments. The two detectors response signals generated large *P*-values ($P > 0.05$) which show that there is no compelling evidence that there are statistically significant differences between the IQM and MatriXX response signals.

5. Discussion

An efficient QA device can detect small misalignment in measurements. This study shows that the two QA devices are sensitive to intentional misalignment in the MLC leaves and jaws of segments considered. From this study, error detection capability is more pronounced in the IQM response signal than in that of MatriXX. This does not mean that the IQM system is more sensitive than the MatriXX device. The fact that they both have a significant correlation to positional errors shows that the difference could be due to issues with calibration of the detectors and large chamber size of the IQM detector, which can extrapolate its response signals. The response signal of the detectors shows that they are both sensitive to alterations in the *x*-axis (MLC modification) and *y*-axis (jaw modification). However, a related study has stated that the sensitivity of the IQM varies slowly along the non-gradient direction (*y*-axis),[10] but is inconspicuous in this study since $10 \times 10\,cm^2$ is the maximum field size considered.

Table 4 shows the IQM and MatriXX responses to dose escalation of 3D-CRT patients' treatment plan. As shown in the table, an increase in dose escalation causes an increase in signal response. For IQM response signals, P_c values were within the ranges of 0.35–8.23%, 0.78–16.21%, and 1.10–24.41% for dose errors of 1%, 2%, and 3%, respectively, of the original plan dose. In addition, for MatriXX response signals, P_c of intentional dose errors at 1%, 2% and 3% of the patients' plan dose to head and neck, thorax and prostate regions fall within 0.24–3.19%, 0.57–6.43% and 0.81–12.95%, respectively. The two detectors are sensitive to dose escalation. Comparison of the IQM and MatriXX response signal ($P < 0.05$) is segment specific, a majority showed statistically significant differences while

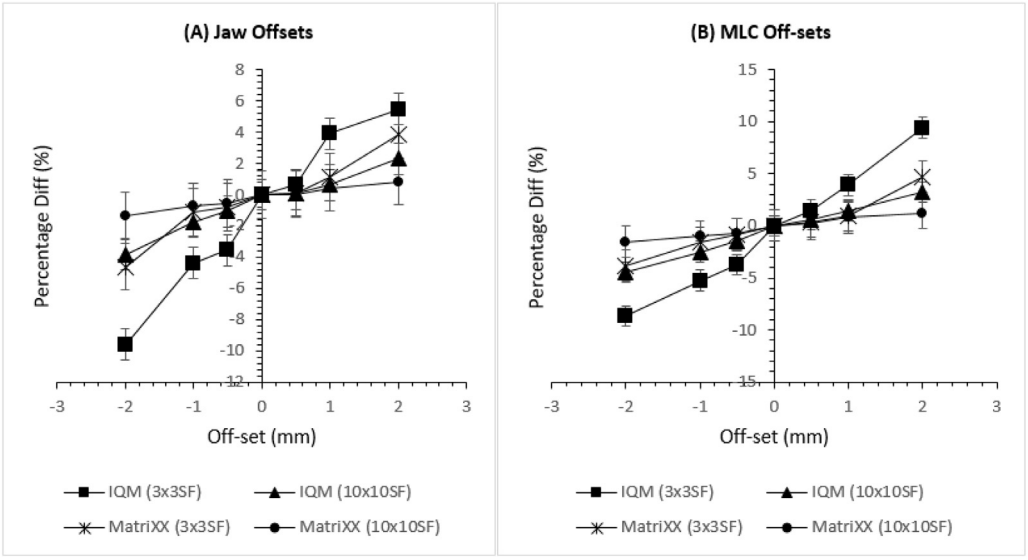

Fig. 8 – Error detection capability for IQM and MatriXX detector signals to error in (A) back-up jaw errors and (B) MLC errors.

Table 3 – Correlation coefficient and P-values for back-up jaw and MLC error analysis.

Offsets	Field size (cm^2)	Correlation $R^2 \pm$ err		P-value
		IQM	MatriXX	
Jaw positions	3×3	0.968 ± 1.002	0.942 ± 0.674	1.000
	10×10	0.971 ± 0.364	0.981 ± 0.112	0.798
MLC positions	3×3	0.988 ± 0.746	0.947 ± 0.661	0.898
	10×10	0.993 ± 0.235	0.973 ± 0.181	0.898

others showed similarities. Uniqueness of each plan alongside with different inherent uncertainties, resolution and calibration of IQM and MatriXX detectors could have caused the inconsistency.

Previous articles have lucidly stated that the array of detectors have a low spatial resolution (typically > 7 mm), which tends to limit their sensitivity.[24] The large ionisation volume tends to generate low sensitivity to dose in the active region, but IQM has not shown any inherent snag in the sensitivity of the detector compared to small arrays of ionisation chambers of the MatriXX detector. In addition, at this stage, the IQM system cannot calculate the dose in the patient as with the MatriXX compass system. Both systems have their advantages. The IQM can measure real-time beam output and benchmark the treatment quality against a set baseline measurement.

Conventionally, 3D-CRT planning is manually optimised and can be validated by scanning the ionisation chamber and verifying MU calculations. These plans (3D-CRT) are relatively large, low fluence gradient with few segments and they are less affected by patients' motion in real-time treatment. Initial test of this study scanned the two ionisation chambers and evaluated their performance. IQM and MatriXX show adequate potential for pre-treatment verification of 3D-CRT plans.

Ionisation chambers are widely used in pre-treatment plan verification since their signal responses are stable with independent beam quality response, low directional dependence, linear, and can be calibrated to a water phantom dosimetry. This study has shown that detectors' (ionisation chamber) huge geometrical difference has little influence on their response signals if they are calibrated to the same scale. Exception is the underestimation of the measured output for a small static field due to the volume averaging effect which is solvable by using a small pixel with high-spatial resolution detector.[24] Having both small pixel and large chamber detectors will definitely complement their limitations.

We have shown that the double wedge-shaped and arrays of small pixel ionisation chambers using 3D-CRT patient treatment plans are sensitive to planar dose errors. In addition, the large chamber of the IQM has not caused any known positioning inaccuracies in the sensitivity study of our 3D-CRT plans since average dose calculation in the active chamber region is not our concern at this point. It is still an on-going study on how to correlate the IQM signal with dose.

Our comparison of the sensitivity of the IQM and MatriXX QA systems using the Mann–Whitney test has shown that positional errors versus response signals have good correlation coefficients. This shows similarities in response signals of the QA systems. Inherent uncertainties and other differences related to each detector alongside with patient specific plans have caused inconsistency between the IQM and MatriXX detectors. Even with increasing dose errors, patient's plan of the same treatment site has dissimilar P-values.

Also, our study has shown that the detectors are sensitive to dose error of 1%. This alteration could be of clinical irrelevance, especially in immoveable tumour site and when organs at risk (OARs) are minimally exposed to irradiated beams. For clinical usage, the purpose of planar verification will definitely influence our focus. For example, if our focus is on what kind of error we want to see, both detectors will generate a different response signal, but with the MatriXX detector, we can see the source of error. IQM generates a numerical value for each segment unlike MatriXX that generates a dose map in

Table 4 – Error detection capability for IQM and MatriXX detector signals to dose errors in 3D-CRT plans (head and neck, thorax and pelvis plans).

Treatment site	Field	IQM signal (% diff)				MatriXX signal (mGy)				P-value			
		0%	1%	2%	3%	0%	1%	2%	3%	1%	2%	3%
H&N1	F1	53,213.93	57,624.12 (8.23)	61,626.76 (15.81)	66,017.83 (24.06)	103.21	106.32 (3.01)	108.81 (5.43)	114.30 (10.76)	0.0001	0.0001	0.0001
	F2	70,499.73	76,163.17 (8.03)	81,926.18 (16.21)	87,709.59 (24.41)	103.52	106.81 (3.19)	109.93 (6.43)	116.93 (12.95)	0.0001	0.0001	0.0001
Thorax	F1	50,657.02	50,659.43 (0.35)	50,690.68 (0.78)	50,707.51 (1.10)	123.43	123.70 (0.24)	124.10 (0.57)	124.43 (0.81)	0.0104	0.0016	0.0001
	F2	364,689.34	369,138.00 (1.22)	373,165.61 (2.33)	377,543.32 (3.53)	174.62	176.06 (0.80)	178.11 (2.01)	180.51 (3.34)	0.0236	0.0088	0.0001
	F3	167,398.07	179,903.51 (3.69)	179,903.50 (7.47)	186,130.31 (11.19)	137.14	138.5 (1.02)	140.61 (2.55)	143.81 (4.89)	0.0001	0.0001	0.0001
Pelvis	F1	2,205,455.22	2,232,325.00 (1.22)	2,255,078 (2.25)	2,275,126.01 (3.16)	408.43	410.33 (0.47)	416.33 (1.93)	419.61 (2.74)	0.0036	0.0001	0.0001
	F2	1,973,899.17	1,991,602.01 (0.90)	2,012,322.20 (1.95)	2,031,076.03 (2.90)	403.71	406.76 (0.74)	411.51 (1.93)	413.63 (2.45)	0.0001	0.1619	0.0003
	F3	121,701.14	123,183.11 (1.22)	123,982.00 (1.87)	125,402.22 (3.04)	86.32	86.62 (0.35)	87.11 (0.93)	88.00 (1.97)	0.0001	0.0001	0.0001
H&N2	F1	34,625.85	34,807.15 (0.52)	35,457.44 (2.40)	35,879.28 (3.62)	83.84	84.17 (0.36)	84.83 (1.19)	85.50 (2.03)	0.7077	0.0001	0.0001
	F2	19,397.80	19,516.29 (0.61)	19,678.31 (1.45)	19,932.23 (2.76)	65.81	66.11 (0.46)	66.92 (1.67)	67.52 (2.54)	0.0504	0.0344	0.0961

2D, 3D and beam profiles. It is easy to see the source of error either in the penumbra or the flat panel of the MatriXX reading display on the OmniPro-I'mRT software. Institutional QA procedure should focus on their planar geometric and treatment sites in order to design an efficient QA procedure. A single QA device may not be capable of obtaining an optimum accuracy for all treatment sites and tumour sizes. This study has evaluated the sensitivity of the IQM and MatriXX detector and it has discovered that the planar dose error detection is patient specific.

6. Conclusion

In this work, the IQM and MatriXX detectors are sensitive to minimal MLC and Jaws positional errors of 0.5 mm and 1% dose escalation in 3D-CRT patient treatment plans. The dosimetric performance of the two commercial ionisation chambers in this study was accurate for pretreatment QA and sensitive to photon beams. We found in the stability analysis for both detectors that they are suitable for pretreatment QA having satisfied the required characteristics of a clinical dosimetry detector.

Conflict of interest

None declared.

Financial disclosure

This research project was funded by the South African Medical Research Council (MRC) with funds from National Treasury under its Economic Competitive and Support package. This research and the publication thereof is the result of funding provided by the SAMRC under the High Energy Advanced Radiation (HARD) sponsorship programme SAMRC-RFA-UFSP-01-2013/HARD.

Acknowledgement

This research project was funded by the South African Medical Research Council (MRC) with funds from National Treasury under its Economic Competitive and Support package. This research and the publication thereof is the result of funding provided by the SAMRC under the High Energy Advanced Radiation (HARD) sponsorship programme SAMRC-RFA-UFSP-01-2013/HARD.

Mr. Itumeleng Setilo for PTW farmer chamber set-up.

REFERENCES

1. Thariat J, Hannoun-Levi J-M, Sun Myint A, Vuong T, Gérard J-P. Past, present, and future of radiotherapy for the benefit of patients. *Nat Rev Clin Oncol* 2013;**10**:52–60.
2. Bindhu J, Supe S, Pawar Y. Intensity modulated radiotherapy (IMRT) the white, black and grey: a clinical perspective. *Rep Pract Oncol Radiother* 2009;**14**:95–103.
3. Chung J, Kang S, Choi K, Suh TS. Comparison of dosimetric performance among commercial quality assurance systems

for verifying pretreatment plans of stereotactic body radiotherapy using flattening-filter-free beams. *J Korean Med Sci* 2016:1742–8.
4. Herzen M, Todorovic F, Cremers, et al. Dosimetric evaluation of a 2D pixel ionization chamber for implementation in clinical routine. *Phys Med Biol* 2007;**52**:1197–208.
5. Wendling M, Louwe RJ, McDermott LN, et al. Accurate two-dimensional IMRT verification using a back-projection EPID dosimetry method. *Med Phys* 2006;**33**:259–73.
6. Myers P, Stathakis S, Buckey C, Papanikolaou N. VMAT monthly QA using two techniques: 2D ion chamber array with an isocentric gantry mount and an in vivo dosimetric device attached to gantry. *J Radiother Pract* 2013;**13**:240–6.
7. Wong JH, Fuduli I, Carolan M, et al. Characterization of a novel two dimensional diode array the "magic plate" as a radiation detector for radiation therapy treatment. *Med Phys* 2012;**39**:2544–58.
8. Poppe B, Looe HK, Chofor N, et al. Clinical performance of a transmission detector array for the permanent supervision of IMRT deliveries. *Radiother Oncol* 2010;**95**:158–65.
9. Stelljes TS, Harmeyer A, Reuter J, et al. Dosimetric characteristics of the novel 2D ionization chamber array OCTAVIUS Detector 1500. *Med Phys* 2015;**42**:1528–37.
10. Islam MK, Norrlinger BD, Smale JR, et al. An integral quality monitoring system for real-time verification of intensity modulated radiation therapy. *Med Phys* 2009;**36**:5420–8.
11. Casar B, Pasler M, Wegener S, et al. Influence of the integral quality monitor transmission detector on high energy photon beams: a multi-centre study. *Zeit Med Phys* 2017:1–11, http://dx.doi.org/10.1016/j.zemedi.2016.10.001.
12. Shimohigashi Y, Araki F, Tominaga H, et al. Angular dependence correction of MatriXX and its application to composite dose verification. *J Appl Clin Med Phys* 2012;**13**:81–96.
13. Sanatorium HK, Valley H, Kong H. Quality assurance of TomoDirect treatment plans using I'mRT MatriXX. *Biomed Imaging Interv J* 2012;**8**:1–7.
14. Li JG, Yan G, Liu C. Comparison of two commercial detector arrays for IMRT quality assurance. *J Appl Clin Med Phys* 2009;**10**:62–74.
15. Poppe B, Belchschmidt A, Djouguela A, et al. Two-dimensional ionization chamber arrays for IMRT plan verification. *Med Phys* 2006;**33**:1005–15.
16. Hoffman D, Chung E, Hess C, Stern R, Benedict S. Characterization and evaluation of an integrated quality monitoring system for online quality assurance of external beam radiation therapy. *J Appl Clin Med Phys* 2017;**18**:40–8.
17. Deshpande S, McNamara AL, Holloway L, Metcalfe P, Vial P. Feasibility study of a dual detector configuration concept for simultaneous megavoltage imaging and dose verification in radiotherapy. *Med Phys* 2015;**42**:1753–64.
18. Oderinde OM, Du Plessis F. Sensitivity analysis of the integral quality monitoring system® using Monte Carlo simulation. *Comput Math Methods Med* 2017;**2017**:1–12.
19. Saito M, Sano N, Shibata Y, et al. Comparison of MLC error sensitivity of various commercial devices for VMAT pre-treatment quality assurance. *J Appl Clin Med Phys* 2018;**19**:87–93.
20. Oderinde OM, du Plessis F. Technical note: A new wedge-shaped ionization chamber component module for BEAMnrc to model the integral quality monitoring system®. *Radiat Phys Chem* 2017;**141**:346–51.
21. Oinam AS, Singh L, Sharma SC, Goswami P. Improvement of I'mRT MatriXX in terms of spatial resolution and large area acquisition for patient-specific intensity-modulated radiotherapy verification. *J Med Phys* 2009;**34**:153–60.
22. Lin L, Kang M, Solberg TD, et al. Use of a novel two-dimensional ionization chamber array for pencil beam scanning proton therapy beam quality assurance. *J Appl Clin Med Phys* 2015;**16**:270–6.
23. IEC. *Medical electrical equipment-dosimeter with ionization chambers and/or semi-conductor detectors as used in X-ray diagnostic imaging IEC 61674*; 1997.
24. Low DA, Moran JM, Dempsey JF, Dong L, Oldham M. Dosimetry tools and techniques for IMRT. *Med Phys* 2011;**38**:1313–38.
25. Zhu TC, Ahnesjo A, Lam KL, et al. Report of AAPM Therapy Physics Committee Task Group 74: in-air output ratio, Sc, for megavoltage photon beams. *Med Phys* 2009:5261–91, http://dx.doi.org/10.1118/1.3227367.