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Assessment of flatness and symmetry of megavoltage x-ray beam with an electronic portal imaging device (EPID)

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Abstract

The input/output characteristics of the Wellhofer BIS 710 electronic portal imaging device (EPID) have been investigated to establish its efficacy for periodic quality assurance (QA) applications. Calibration curves have been determined for the energy fluence incident on the detector versus the pixel values. The effect of the charge coupled device (CCD) camera sampling time and beam parameters (such as beam field size, dose rate, photon energy) on the calibration have been investigated for a region of interest (ROI) around the central beam axis. The results demonstrate that the pixel output is a linear function of the incident exposure, as expected for a video-based electronic portal imaging system. The field size effects of the BIS 710 are similar to that of an ion chamber for smaller field sizes up to 10 x 10 cm^2. However, for larger field sizes the pixel value increases more rapidly. Furthermore, the system is slightly sensitive to dose rate and is also energy dependent. The BIS 710 has been used in the current study to develop a QA procedure for measurements of flatness and symmetry of a linac x-ray beam. As a two-dimensional image of the radiation field is obtained from a single exposure of the BIS 710, a technique has been developed to calculate flatness and symmetry from a defined radiation area. The flatness and symmetry values obtained are different from those calculated conventionally from major axes only (inplane, crossplane). This demonstrates that the technique can pick up the "cold" and "hot" spots in the analysed area, providing thus more information about the radiation beam. When calibrated against the water tank measurements, the BIS 710 can be used as a secondary device to monitor the x-ray beam flatness and symmetry.

Key words electronic portal imaging device, quality assurance

Introduction

Electronic portal imaging devices

On-line portal imaging systems were originally developed to acquire digital images of transmitted fluence during radiotherapy treatments. Since their inception, most on-line portal imaging studies have concentrated on verification of set up geometries, such as the radiation beam size, shape and location relative to anatomical structures[1,2,3,4,5]. In the last few years, their potential for dosimetric purposes was investigated. These dosimetric applications fall into two main categories: the measurement of transmitted dose (i.e. two-dimensional dose maps)[6,7,8] and the design of compensators to achieve the desired dose[9,10].

On-line imaging systems can also be used effectively to measure parameters required for treatment planning and equipment quality control[11,12.13,14], such as verification of the isocentre position, interleaf transmission of the MLC, dose distribution profiles, light field and radiation field coincidence and energy constancy. Kirby and Williams[12] have investigated the use of a video-based EPID (Philips SRI-100) to test the field flatness and symmetry along the beam diagonals. Ma et al[13,14] used a Wellhofer Beam Imaging System (BIS 710)[a] to verify applicability for measurement of the light and radiation field coincidence, electron energy constancy, x-ray beam flatness and symmetry, and collimator and couch rotation axes. The suitability for the flatness and symmetry evaluation was tested by measuring the systematic flatness and symmetry variations from 3% to 30%, produced by custom-made aluminium wedges. Comparative measurements were made against a radiation beam analyser device (RBA-5, Gammex RMI) and it was concluded that BIS 710 was more sensitive to the flatness and symmetry variations. However, similar to conventional techniques, the authors only analysed the crossplane and inplane directions.

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Flatness and symmetry of a radiation beam

A major requirement in radiotherapy is that the dose variation over the target volume is limited so that all points in the volume receive the prescribed dose within a tolerance range. In IEC protocols, the beam flatness and symmetry are defined in an area[15] (shown in Figure 1) at 10 cm water depth. The flatness of the x-ray beam is defined by the following formula[15]:

$$\text{Flatness}\,(\%) = \frac{D_{max}}{D_{min}} \times 100\% \qquad (1)$$

where D_{max} and D_{min} are the maximum and minimum doses respectively within the area.

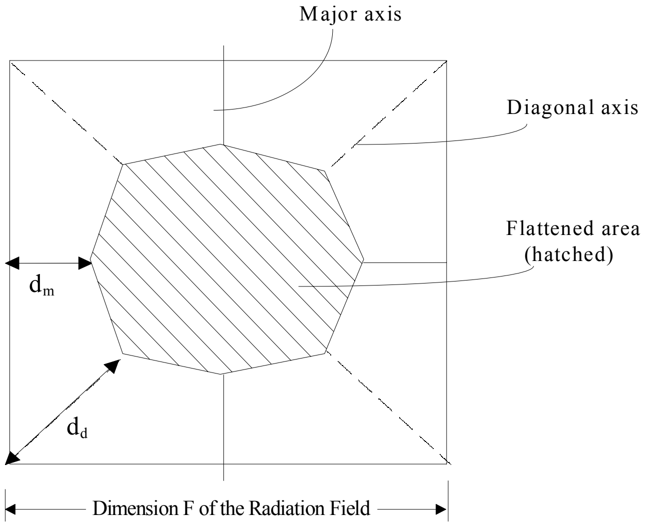

Figure 1. *Flattened area (shown hatched) within the radiation field. The values of d_m and d_d are defined for different radiation field sizes in IEC, 976[17].*

Radiation field symmetry is defined as the maximum ratio of doses at two symmetric points relative to the central axis of the field[15]:

$$\text{Symmmetry}(\%) = \left|\frac{D(x,y)}{D(-x,-y)}\right|_{max} \times 100\% \qquad (2)$$

Conventionally, beam flatness and symmetry are investigated with a computer-controlled scanning water tank system and the absolute values of the beam flatness and symmetry are measured at a reference depth. The set up procedure for this technique is time consuming and consequently unsuitable for regular quality assurance testing. For short interval quality assurance purposes, one dimensional detector arrays or specially designed phantoms are commonly used. However, all these devices (including the water scanning system) provide results for just one specific direction (e.g. inplane, crossplane and along the diagonal axes) at a time. A two dimensional distribution may be obtained, e.g. with the water tank set up, by extensive scanning along the two-dimensional area investigated. As this is a very time consuming procedure, major axes only are typically scanned for routine QA purposes. On the other hand, on-line imaging systems have the ability to provide two dimensional dose distributions from a single exposure, making the acquisition of data faster and the investigation of these beam parameters more comprehensive as the whole radiation area is evaluated. Compared to radiographic films, which also provide 2D maps, there is no need for processing and scanning before analysis as the radiation field can be analyzed on-line.

BIS 710

The Wellhofer BIS 710 is a video-based electronic portal imaging device (EPID). It consists of a gadolinium (Gd_2O_2S) fluorescent phosphor screen preceded by a 1.0 mm copper build-up layer, a CCD camera, and a frame grabber with a 10 bit image depth. The camera has an active 500 × 500 pixel array which can view an area of up to 30× 30 cm^2 on the screen.

The signal standard of the CCD camera is CCIR, i.e. 50 frames/second. The system software provides for adjustment of sampling times (the integration time in the CCD matrix) and sampling numbers. A sampling time of 960 ms will integrate 48 video frames, pre-ADC (Analog to Digital Converter). The sampling number is the number of images averaged (or integrated) post-ADC. A typical setup with 960 ms sampling time and a sampling number of 25 will average 25 images with each image consisting of 48 summed video frames pre-ADC (see Figure 2).

In this paper, the application of the WellhOfer Dosimetrie BIS 710[16] system to periodic checks of flatness and symmetry of the radiation beam has been investigated. In the first step, the EPID's performance has been studied (measured characteristics of the BIS 710 system being discussed in the following sections). In the second step, the procedure for routine flatness and symmetry check has been developed.

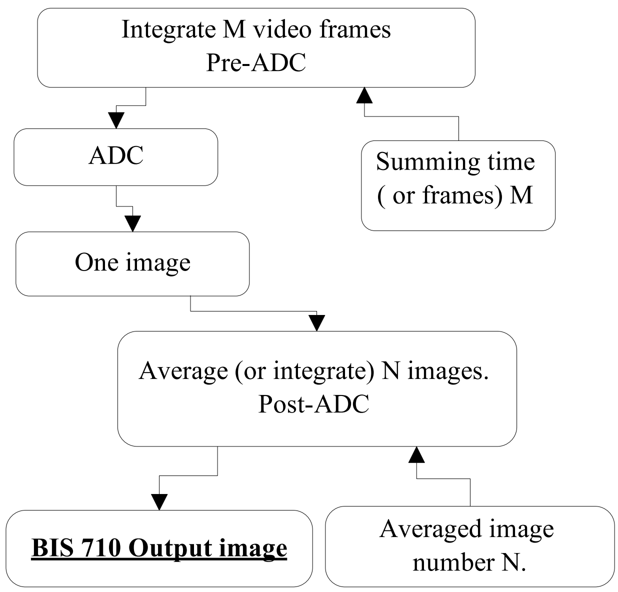

Figure 2. *The flow chart shows how to sum M video frames. Averaging (or integrating) of N images produces a BIS 710 output image.*

Materials and Method

The sensitivity correction for BIS 710 output images

The region of interest (ROI) used in this study is 10 × 10 pixel^2 unless specified otherwise.

The pixel elements in the BIS 710 output image need to be processed with i) a correction image (provided by the manufacturer) and ii) a dark or background image (measured directly before the radiation beam image acquisition). The manufacturer provides an individual correction image for each BIS 710 system. This image was measured using a well-designed uniform x-ray beam geometry to account for the differences in individual pixel sensitivity[16] due to the following system-relevant parameters: (a) decreasing light intensity between the centre and edges of the optical system, (b) inhomogeneity of the scintillator (c) sensitivity differences of the CCD matrix, and (d) the dark current of the CCD camera.

For every x-ray image acquired in this study, a corresponding background image was measured with the same parameter settings but with the radiation switched off. The correction formula for a measured radiation image was:

$$P(i,j) = [P_0(i,j) - P_b(i,j)] \times P_c(i,j)/4096 \qquad (3)$$

where P(i,j) is a pixel value of the corrected radiation image, $P_0(i,j)$ is the pixel value of the measured radiation image, and $P_b(i,j)$ is the pixel value of the dark image at point (i,j) on the imaging screen. $P_c(i,j)$ is the correction matrix provided by the manufacturer. This correction method is different from the commonly used correction shown below:

$$P(i,j) = [P_0(i,j) - P_b(i,j)]/P_c(i,j) \qquad (4)$$

Equation (3) provides the benefit of fixed scaling (normalisation) of the pixel values of the corrected radiation images, making the corrected images from different measurements comparable to each other[16].

Reproducibility of the BIS 710

The reproducibility of the BIS 710 was measured by acquiring ten consecutive flood field (radiation) images with the same settings. The reproducibility is determined as a relative deviation from the mean using the formula[17]:

$$s = \frac{100}{\bar{R}}\sqrt{\sum_{i=1}^{n}\frac{(\bar{R}-R_i)^2}{n-1}} \qquad (5)$$

where R_i is the pixel value measured from the BIS 710 image within a ROI. $\bar{R}$ is the average of R_i and n is the number of measurements.

Long term reproducibility (over time) of BIS 710 has not been investigated in the current work.

Build-up layer measurements

The intrinsic BIS 710 detector thickness (1 mm Cu plus scintillation layer) is insufficient to reach electronic equilibrium at the position of the Gd_2O_2S layer (midplane of scintillation layer) at megavoltage photon energies. If the BIS 710 is used without extra build-up material, its detector is situated in the dose build-up region where measured pixel values are affected by contamination electrons and low energy scattered photons produced in the treatment head. To avoid this, an additional build-up layer is required. The amount of the build-up material needed was determined by increasing the thickness of solid water slabs, placed on top of the EPID housing, in steps of 2 mm until a maximum pixel reading was obtained. The amount of build-up layer required was measured for two x-ray energies of a Siemens KD-2 medical linear accelerator (6 and 23 MV), at 100 cm source-to-surface distance and 10 × 10 cm^2 field. During all subsequent experiments the determined build-up layer was used to obtain electronic equilibrium in the detector.

Dose and dose rate response curve of the BIS 710

The BIS 710 pixel output value was measured as a function of monitor units, using a 6 MV x-ray beam from Siemens KD-2 linac. The source to surface distance was 100 cm, and field size used was 10×10 cm^2. The system must be set into the integration mode to allow cumulation of pixel value with dose. Integration of too many images will cause pixel overflow (the value will roll over to 0).

A sampling time of 960 ms was chosen for the measurements; no pixel value overflow was observed for this time selection. Since synchronisation of the radiation beam and the imaging system cannot be achieved, the BIS 710 was switched on before the beam was turned on and finished acquiring after the beam was turned off. All the video frames were added to form a final image. Two dose rates, 200 MU/min and 100 MU/min, were used to test the dose rate dependence. The average pixel output values were calculated from the ROI.

The Varian accelerator 21EX installed at Royal Adelaide Hospital produces x-ray beams with 6 dose rates and allows a comprehensive test of the dose rate dependence of the BIS system. Images were acquired with dose rate from 100 MU/min to 600 MU/min and with the same settings for all other parameters. 200 MU were delivered to each image. The pixel values were calculated from a ROI (10 × 10 pixels) around the radiation field centre.

Pixel size and spatial linearity measurement

Pixel size needs to be calculated, if BIS 710 is to be used for verification of the radiation field size as well as for definition of the flatness and symmetry area within the radiation fields. The pixel size (at the isocentric plane) can be obtained by comparing the physical field size (which is given by the digital scales) and the measured field size in pixel numbers. The spatial linearity, which can also identify any image distortion, is checked by measuring a range of different field sizes. To measure the pixel size in the inplane and crossplane axis of the BIS 710, images were acquired for different field sizes from 2×2 cm^2 to 25×25 cm^2 with the detector placed at 100 cm SSD. The pixel values from the ROI around the beam centre was taken as the 100% energy fluence value. The radiation field edges were defined as 50% of this value. From the field edge positions, radiation field sizes in image pixel numbers were obtained and plotted against their physical field sizes (field sizes given by linac digital scales were checked against a water tank measurement and found accurate within ± 0.5 mm). The pixel size in inplane and crossplane directions is then determined from the slope of the fitted line.

BIS 710 field size response for fixed MU

In order to investigate the dependence of the pixel value of the BIS 710 on the field size, images were acquired for field sizes from 5 × 5 cm^2 to 25 × 25 cm^2 and irradiated with the same number of monitor units. The mean pixel values from a 10 × 10 pixels region in the field centre were calculated and ion chamber readings within a solid water phantom were recorded in order to make a comparison. The results from both measurements were plotted against the field size.

Energy response

Since modern linacs produce multiple beam energies and the beam energy spectrum will change after the beam passes through a thickness of phantom before reaching the imaging system, it is necessary to know the energy response of the system. Two x-ray energies, 6 MV and 23 MV, from the Siemens KD-2 linear accelerator and a 4 MV x-ray from a Varian 4/100 were used to investigate the energy dependence of the system. Images were acquired for monitor units varying from 20 to 400 MU to obtain response curves for different incident energies.

The effect of the sampling time on the pixel value

The output pixel value of BIS 710 depends on the sampling time selected. If used in integration mode (i.e. all images are summed up), a larger sampling time produces a larger pixel value because the signals are integrated over a longer time. In order to take advantage of the dynamic range of the bit depth, a sampling time is selected which produces a pixel value about 800 ~ 900. Also, it is essential for dosimetry purposes that pixel values are comparable for different settings of the acquisition parameters. In order to investigate the relationship between pixel values and sampling time, a series of images with different sampling times, from 480 ms to 2400 ms, were acquired. The mean pixel values were calculated from the ROI in the centre of the radiation fields. The obtained pixel values were then plotted against the sampling time.

BIS 710 scatter response

Because the scatter conditions between the BIS 710 measurements and an ion chamber measurements are always different, it is useful to compare the BIS and ion chamber response to the scattered radiation. An experiment was carried out by varying the distance from the exit surface of 20 cm solid water phantom to the detector surface. The detector to source distance is fixed to 150 cm. Ion chamber measurements were taken with the ion chamber placed at depth of maximum dose in a 40 × 40 cm solid water plate (1 cm of solid water behind the ion chamber to minimize the backscatter) while BIS detector was covered with additional build-up layer. The photon beam energy used was 6 MV photon. The setup geometry is shown in figure 3.

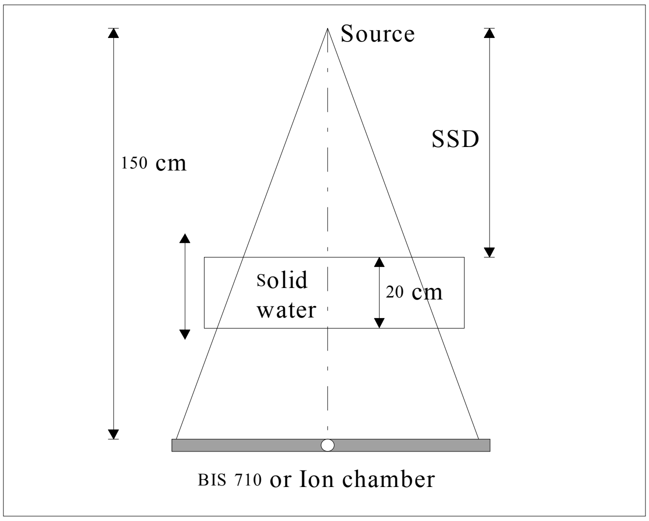

Figure 3. *The setup geometry of BIS 710 scatter response measurements. Field size of 10 × 10 cm, and 200 MU were used.*

Radiation field flatness and symmetry assessment with BIS 710

With most of the characteristics of the BIS 710 determined, the efficacy of its application to flatness and symmetry of megavoltage x-ray beams could be assessed. As it was intended to use BIS 710 as a secondary device for constancy checks of linac's flatness and symmetry, the measurements were not preformed at 10 cm depth in a water equivalent material (as defined in IEC protocols[15]) but at the maximum dose depth. A 6 MV photon beam of 25 × 25 cm^2 field size (Siemens KD-2 linear accelerator) was used to irradiate the BIS 710 with the additional build-up layer on top of the apparatus. A 960 ms sampling time was selected, corresponding to averaging of 25 images (48 frames each). A computer program was written to locate an area in the image, defined by IEC protocol[15], automatically (Figure 4) and to calculate the flatness and symmetry within that area using formulas (1) and (2), respectively (unlike conventional methods that calculate the flatness and symmetry from the main axes only).

Due to specifics of the BIS 710 assembly construction, the amount and sources of scattered radiation reaching the phosphor screen needed to be investigated as the scatter would differ from that present when using water tank and ion chamber set up for the same field size and depth. A different scatter component could affect the measured values of flatness and symmetry especially if BIS is energy dependent. In order to assess the sources of scattered radiation affecting the BIS 710 images, the following tests were undertaken with radiographic film (Kodak X-OMAT V) as the image recorder:

(a) the gadolinium (Gd_2O_2S) fluorescent phosphor screen was removed from BIS 710 assembly and replaced with a ready pack film in order to investigate the effects of radiation side-scatter from

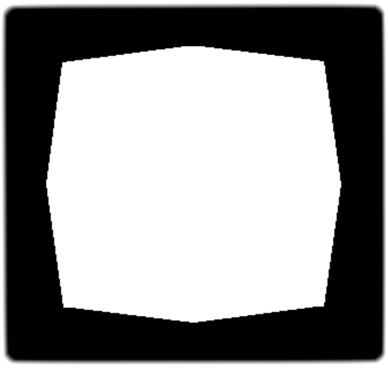

Figure 4. *A BIS 710 image with a defined flatness and symmetry area automatically located by a computer program.*

the EPID housing; the build-up of 1.5 cm was applied so that the film was at the same depth as the detector screen

(b) film was positioned on the couch and covered with BIS (including the copper plate) in order to estimate the effects of the scatter radiation from the detector screen itself (this radiation would reach the optical chain of the detector). 1 cm of additional build up (as in typical measurement set up) was used

(c) film was positioned on the couch with 1.5 cm build-up of solid water to provide a reference image.

In all cases, the films were irradiated with 50 MU, 6 MV x-ray beams. Comparison of the results from (a) and (c) experiments will show the effect of the side-scatter radiation from the EPID housing and comparison of (b) and (c) will show the effect of the scatter produced in the BIS 710 detector on the acquired image.

Calibration of BIS 710

Corrections for the above mentioned scattering effects must be made in order to use the BIS 710 for measurement of flatness and symmetry. Film was chosen to provide a 2-D correction array for a range of field sizes, likely to be used for QA tests, because of the difficulty of getting 2-D ion chamber array scans. The BIS 710 system was setup to acquire images at d_{max} (maximum dose depth) for 6 MV x-ray beam energy and a range of field sizes. Film images were taken at the same time using the same geometry. Film images were digitized, background-subtracted and saved. The film images and the BIS 710 images were aligned by the centres and by the inplane and crossplane profiles and 2-D image ratios were saved as correction arrays. Subsequently acquired BIS 710 images (after the application of the correction array) can be used to investigate the flatness and symmetry of the radiation field.

Results and discussion

Reproducibility of the BIS 710

A reproducibility of ±0.5% of the pixel values of ROI has been determined from our measurements using equation (3). Different parameter settings will cause slightly different reproducibility values due to the variable noise level (not investigated in detail in the current work). The above measurement result was obtained for pixel values of 800~900 recommended by the manufacturer.

Build-up layer measurements

In Figure 5 the relative pixel value readings are shown as a function of additional build-up layer thickness (solid water equivalent) for the 23 MV x-ray beam. A maximum pixel value reading is found at a build-up thickness of 32 mm. For the 6 MV photon beam, 10 mm of solid water is required to ensure electronic equilibrium in the detector screen.

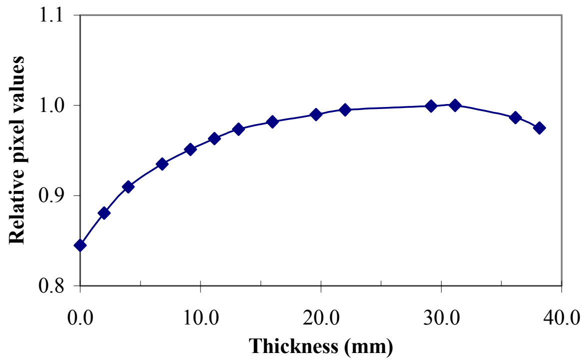

Figure 5. *Determination of additional build-up layer (solid water) required for BIS 710 measurements for 23 MV x-ray beam.*

Dose and dose rate response curve of the BIS 710

The average pixel values were calculated from the ROI around the beam centre and plotted as a function of delivered monitor units (Figure 6). The graph shows that pixel values of the BIS 710 depend linearly on monitor units for 6 MV photon energy from Siemens KD-2 linac. This result agrees with results of Ma et al[13]. It also indicates that the BIS 710 output is slightly dependent on dose rate (maximum 2.5% decrease for a 2 Gy irradiation dose with 200 MU/min compared to 100 MU/min dose rate).

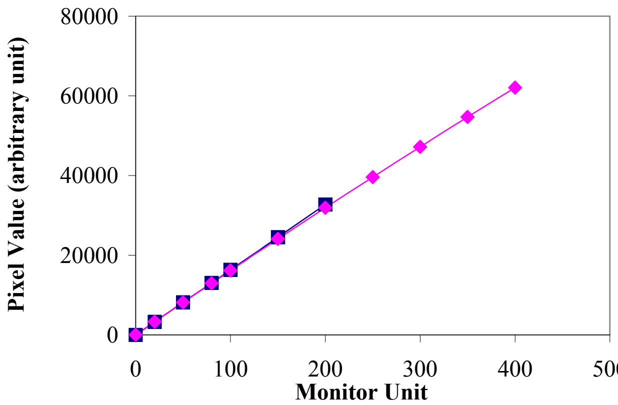

Figure 6. *Dependence of BIS 710 measured pixel value on delivered monitor units for 6 MV photon energy from Siemens KD-2 linac and two dose rates:* ■ *100 MU/min,* ◆ *200 MU/min.*

This finding is further confirmed by the results of dose rate dependence measurement using 6 MV beam from VARIAN 21EX accelerator (shown in Figure 7). A decrease of 3.1% in pixel value has been observed from dose rate of 100 MU/min to 600 MU/min.

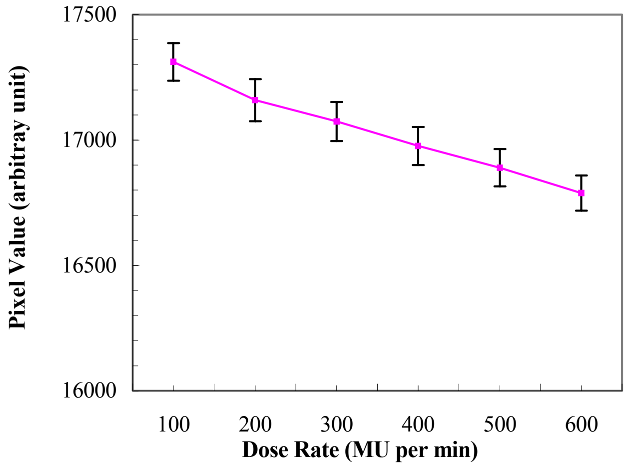

Figure 7. *Dose rate dependence of BIS 710. Measurements were performed on VARIAN 21EX linear accelerator, using 6 MV x-ray beam and dose rates from 100 to 600 MU/min.*

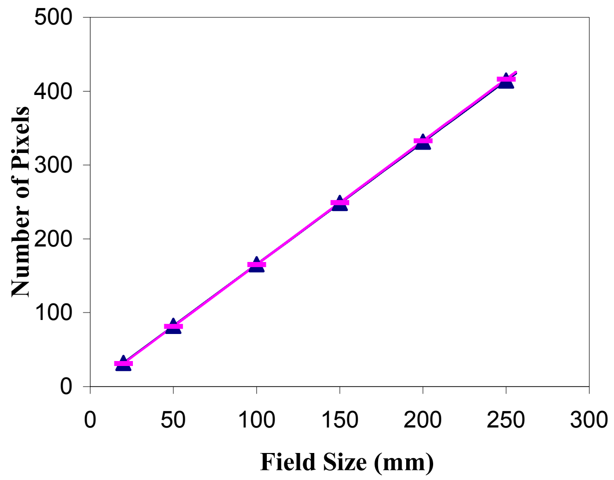

Figure 8. *BIS 710 pixel size determination: ▲ crossplane data, and – inplane data. The two data sets cannot be distinguished.*

Pixel size measurement and spatial linearity

Because of the linear response of pixel value versus dose, the 50% pixel value contour was used as the corresponding 50% dose contour for determination of the imaged field sizes. The imaged field sizes were then calculated from the left/top 50% dose contour to the right/ bottom 50% dose contour of the inplane/crossplane beam profiles. The number of pixels for different field sizes was determined and plotted against the field sizes given by linac digital scales (see Figure 8). The horizontal or vertical pixel size is determined from the slope of the fitted line. From Figure 8, the inplane and crossplane pixel sizes were measured to be 0.598±0.003 mm/pixel and 0.603±0.003 mm/pixel at the isocentre plane, respectively. These results agree within 0.5% with the manufacturer's value of 0.6 mm/pixel. The fitted straight lines also confirm that the spatial linearity of BIS 710 is very good and there are no detectable image distortions.

Field size response for fixed MU

The field size response results are presented in Figure 9, showing the pixel values for different beam field sizes varying from 5 × 5 to 25 × 25 cm^2 with the source to detector scintillation layer distance of 100 cm. The dose measured in a solid water phantom using an ion chamber is also presented in Figure 9. Both data sets were normalised to field size 10 × 10 cm^2. There is a rapid rise in the scatter contribution to pixel value and dose for increasing field size of less than 10 × 10 cm^2 for BIS 710 and ionization chamber respectively. At larger field sizes though, the pixel values of BIS 710 increase more rapidly with field size than doses measured by an ion chamber in a phantom. The ratio of pixel value of BIS 710 to ion chamber reading increasing by 5.6% from field of 5 × 5 cm^2 to 25 × 25 cm^2. This increasing contribution to pixel values can be due to scatter within the phosphor layer itself or due to side scatter reaching from the BIS 710 housing walls, which will be investigated in the following sections.

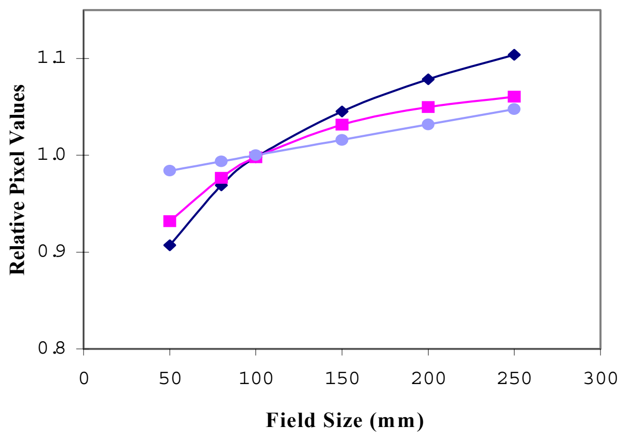

Figure 9. *BIS 710 field size response:* ◆ *BIS 710 results;* ■ *ion chamber readings in a phantom;* ● *the ratio of BIS pixel value and the ion chamber dose readings (all results are for 6 MV x-ray beam).*

Energy response

The output characteristic curves were obtained for 4, 6 and 23 MV x-ray energies. A corresponding thickness of additional build-up material, measured as described in the previous section, was applied for each beam energy. The results are plotted in Figure 10. It is evident that the BIS 710 is energy dependent, with about a 13% increase in response at 400 MU from 4 MV to 23 MV photon energies. There are some concerns about the EPID image quality change after the beam passes through the additional build-up layer. Boellaard *et. al*[7]. showed that for photon beam energy of less than 8 MV there was no significant difference in the image quality between measurements with and without additional build-up layers, however for the 25 MV beam there was a small difference. Since the beam energy will change only by a small amount after passing through the additional build-up layer, the beam hardening caused by the additional build-up layer is negligible. The BIS 710 output is then directly related to the beam energy fluence[14] and can be used to measure the absorbed dose.

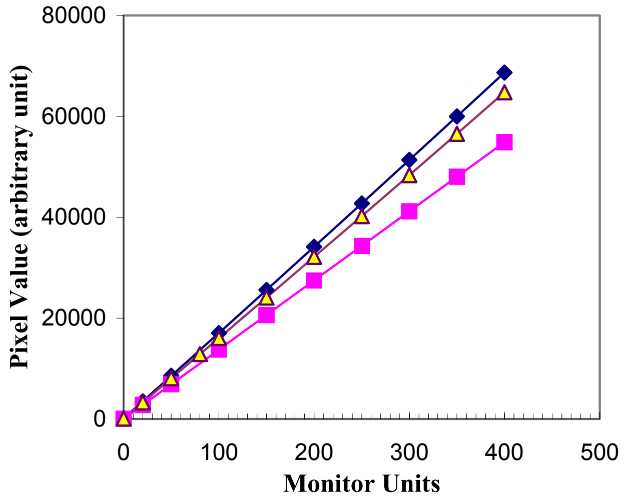

Figure 10. *BIS 710 energy response: ▲ 6 MV x-ray beam at 200 MU/min; ◆ and ■ is 23 MV x-ray beam at 300 MU/min with and without additional build-up layer respectively.*

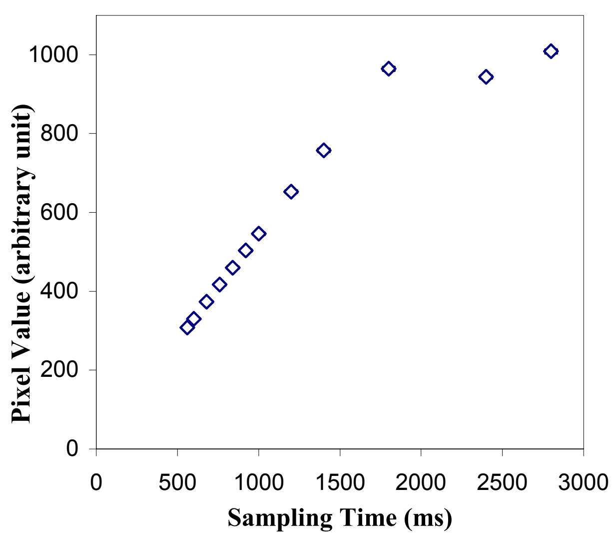

Figure 11. *Dependence of pixel value on BIS 710 sampling time.*

For comparison, Figure 10 also shows the 23 MV calibration curve without additional build-up material. The measured pixel values were smaller than those for 6 MV energy with additional build-up material. This is because the detector is located in the dose build-up region where the system sensitivity is less because of the smaller dose deposited.

The effect of the sampling time on the pixel value

The pixel values versus the sampling time are shown in Figure 11. Below 1.8 s there is a linear relation between the sampling time and pixel values, and a non-linear response is found for sampling times larger than 1.8 s. The manufacturer, however, claimed there is no linear relationship for sampling times larger than 1 s[16]. Sampling times shorter than 1.8 s should be selected if the BIS 710 is used for dosimetry purposes and the relative pixel values can be compared by applying a linear correction factor derived from Figure 11.

BIS 710 scatter response

The results of the scatter response measurement are plotted in figure 12 (the ion chamber readings are re-scaled and normalised to the reading at 100 cm SSD (source to solid water phantom surface/entrance)).

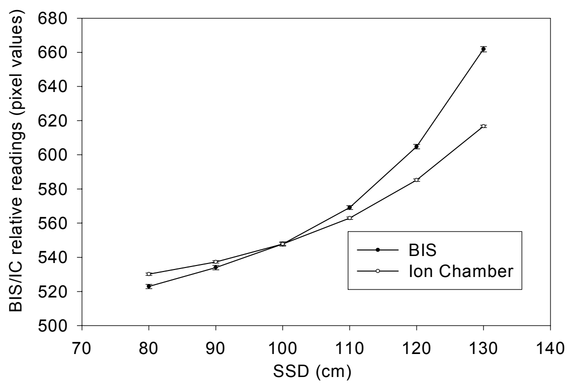

Figure 12. *BIS scatter sensitivity measurements. A 20 cm solid water was used and the SSD were measured from source to surface of the block. Larger SSDs mean smaller distances from phantom exit surface to the detectors.*

The results show that BIS 710 has significantly higher response at a larger SSD (smaller phantom exit surface to BIS 710 detector distance) while at smaller SSDs the BIS 710 has a similar response with an ion chamber. It is concluded that the BIS 710 is more sensitive to the scattered radiation energies (below 1 MV) since the amount of scatter from the solid water phantom represents the only difference for different SSDs. It is therefore assumed that BIS 710 system is more sensitive to lower energies. This behaviour has been observed for other metal/phosphor imaging systems[14].

Radiation field flatness and symmetry assessment

Preliminary investigation showed that 8% flatness was measured using the BIS 710 images for radiation field sizes larger than 25 × 25 cm^2, although the corresponding ion chamber water tank scan result gave ~3%. Figure 13 shows

6 MV Photon	Inplane		Crossplane		Flattened area*	
	Flatness (%)	Symmetry (%)	Flatness (%)	Symmetry (%)	Flatness (%)	Symmetry (%)
BIS 710 (uncorrected)	5.30	0.79	7.20	0.98	8.62	1.12
BIS 710 (corrected)	2.77	0.70	1.91	0.46	2.85	1.01
Film	2.51	0.60	2.25	0.53	2.79	1.12
Ion Chamber	3.20	0.90	3.10	0.50	n/a	n/a

Table 1. *Results of flatness and symmetry check for 6 MV photon beam with radiation field size 25 × 25 cm, expressed as percentages.*

the crossplane beam profile only, measured by BIS 710 with 6 MV photon beam at 25 × 25 cm^2 field size from a Siemens KD-2 linear accelerator. Two horns are apparent near the edges, ~ 8% higher than the central axis dose. Consequently, as 8 % flatness is observed also on the major axis, this high value (as calculated from the defined area of the BIS image) is not due to a hotspot somewhere within the area but a result of the detector response.

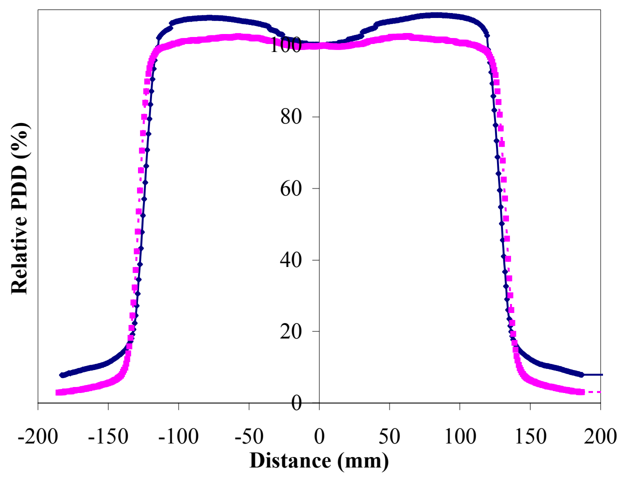

Figure 13. *BIS 710 crossplane beam profile (not-corrected, solid line) and ion chamber measurement (dotted line). Two horns are apparent near the edges, showing a deviation from beam flatness.*

The different response between the BIS 710 and ion chamber measurements may be caused by: (i) side scatter radiation from the metal wall of the BIS 710 housing for larger field sizes; (ii) light scattering effects within the optical chain of the EPID; and (iii) energy dependent response of the BIS 710 detector.

Energy dependence was confirmed by the scatter measurements discussed above. Also, Jaffray *et. al*[18] has showed that a similar metal/phosphor screen was much more sensitive to low radiation energy. This can partially explain the production of the horns because there are more low energy x-rays near the beam edges after the beam passes through flattening filter and the treatment head.

The results of radiographic film tests, described in previous section and intended to identify the sources and amounts of scattered radiation for BIS 710 measurements, confirm that:

(i) There is no detectable difference between the film images from tests (a) and (c).

(ii) There is no detectable difference between the radiation beam profile under the BIS 710 radiation detector and without detector (test b), except for a broader penumbra.

From the above results, it can be concluded that there is no or minimal effect from the radiation backscattered from BIS 710 housing and the BIS 710 radiation detector itself does not cause the 'horns'. This would indicate that it is the design of the optical system within the BIS 710 housing that contributes to the 'horns' as well as higher response of the detector screen to lower radiation energies.

The results of beam flatness and symmetry of a 6 MV photon beam from a Siemens KD-2 linac are presented in Table 1. Table 1 shows that the results from BIS 710 (after applying correction/calibration) and film agree well within 1.2%. This technique calculates flatness and symmetry from a defined area, and the maximum un-flatness and asymmetry are different from the values calculated from major axes only. It demonstrates that this technique can easily pick up the "cold" and "hot" spots in the defined area, therefore it provides more information about radiation field flatness and symmetry.

As flatness and symmetry measurements from film and ion chambers are comparable, films provide a reasonably accurate correction/calibration matrix for BIS 710 images. As a secondary standard device, the BIS 710 can be used to monitor the x-ray beam flatness and symmetry. When it shows that flatness or symmetry are outside specified limits, the computer controlled water scanning system can be used to provide more accurate measurements.

Conclusion

The input/output characteristics of the BIS 710 have been investigated to better understand its basic imaging properties, with the aim of developing periodic quality assurance applications using the device, concentrating on the beam flatness and symmetry aspect of QA in the present paper. Calibration curves have been measured to quantify the relationship between the energy fluence incident on the detector and pixel values. The effect on the beam parameters, such as beam field size, dose rate, photon energy, and sampling times have also been investigated in a ROI of 10 × 10 pixels around the central beam axis. The results demonstrate that the pixel value is a linear function of the incident monitor units, which is typical for video based portal imaging system[19, 9]. The field size effect of the BIS 710 is similar to ion chamber measurements for smaller field sizes. However, the pixel values increase more rapidly at larger field sizes. The system is slightly sensitive to dose rate (3.1 % from 100 MU/min to 600 MU/min for Varian 21EX) and is energy dependent. A linear relationship has been shown for sampling times under 1.8 s but a non-linear dependence is expected after 2 s.

The beam flatness and symmetry calculations from the BIS 710 images show that it can provide more comprehensive information about these parameters than a simple calculation using major axes only. This enables it to be used as a secondary device to monitor the x-ray beam flatness and symmetry provided that it is properly calibrated. Its use for energy constancy and mechanical checks will be investigated in future works.

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