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Comparison of ghosting effects for three commercial a-Si EPIDs

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Many studies have reported dosimetric characteristics of amorphous silicon electronic portal imaging devices (EPIDs). Some studies ascribed a non-linear signal to gain ghosting and image lag. Other reports, however, state the effect is negligible. This study compares the signal-to-monitor unit (MU) ratio for three different brands of EPID systems. The signal was measured for a wide range of monitor units (5–1000), dose-rates, and beam energies. All EPIDs exhibited a relative under-response for beams of few MUs; giving 4 to 10% lower signal-to-MU ratios relative to that of 1000 MUs. This under-response is consistent with ghosting effects due to charge trapping. © 2006 American Association of Physicists in Medicine. [DOI: 10.1118/1.2207318]

Key words: EPID dosimetry, image lag, ghosting, dose response, amorphous silicon

I. INTRODUCTION

Dosimetry with portal imagers is becoming increasingly popular, offering the potential for multi-dimensional dose verification. There are currently three brands of amorphous silicon electronic portal imaging devices (a-Si EPIDs) commercially available: Elekta iViewGT (Elekta, Crawley, United Kingdom), Varian aS500/1000 (Varian Medical Systems, Palo Alto, California), and Siemens OptiVue 500/1000 (Siemens Medical Solution, Concord, California).

Before using such a device for dose verification, it is necessary to first determine its dosimetric characteristics. Signal-to-dose ratios have been measured for these types of detectors, and found to be non-constant.1,2 A lower signal-to-MU ratio was reported for relatively short irradiation times, up to 10% lower than that of longer irradiation times for the Elekta EPID. The source of the deviation was attributed to image lag and gain ghosting effects. “Image lag” is due to charge trapped in the photodiode bulk modulus or at the surface. Trapped charge read out in subsequent frames results in an off-set of the EPID signal. “Gain ghosting” refers to the change in gain, or pixel sensitivity, due to the trapped charge, which alters the electric field strength in the bulk or surface of the photodiode layer. The extent of both effects (image lag and gain ghosting) will depend on both the panel design and the exposure time. Trapping in the bulk layers effectively involves the “direct capture of charge at defect energy levels in the gap and is followed by the slow release over a broad range of time constants.”3 In particular, the design and manufacture of the diode layer will influence the density of trapping states, and hence influence the way charge is trapped at the diode level. Various reports have investigated image lag and gain ghosting properties of indirect flat panel detectors in further detail.3–6

When using the EPID as a dosimeter, both image lag and gain ghosting effects combine to influence the dose per frame read out by the detector.7 According to our previous study, frames within the first few seconds of irradiation “missed dose.” The longer the irradiation time, the smaller the relative deficit (proportional to the integrated dose over all frames). The EPID signal per frame persisted in the seconds following beam off, gradually decreasing, indicating image lag. When this “lag” (dark signal) was added to the integrated dose, there was still a deficit. This was attributed to gain ghosting effects. For the purposes of MU dependence, and for the remainder of this paper, we refer to the combination of gain ghosting and image lag as “ghosting.” Ghosting effects can cause problems for EPID dosimetry if the imager signal is assumed to be linear with accumulated dose. Discrepancies will arise when the treatment exposure time differs from calibration exposure times.

Other studies, however, have reported a linear dose-signal relationship within 2%.7–12 All of these studies used the
TABLE I. Details of the imagers and acquisition parameters for each set of \( \alpha\)-Si EPID measurements. A signal-to-MU curve was acquired for each EPID on the central axis of square fields, 5 to 1000 MUs, at the dose-rate settings and beam energies indicated. The value of the signal for each measurement was the average pixel value of the central region of interest (ROI) of each detector.

<table>
<thead>
<tr>
<th>EPID</th>
<th>Institute</th>
<th>Acquisition software</th>
<th>Active area</th>
<th>Image resolution</th>
<th>Field size</th>
<th>SDD</th>
<th>Central ROI</th>
<th>Series measured</th>
<th>Beam energy and (dose-rate, MU/min) combinations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elekta</td>
<td>Netherlands</td>
<td>iViewGT</td>
<td>41 × 41 cm(^2)</td>
<td>1024 × 1024</td>
<td>20 × 20 cm(^2)</td>
<td>160 cm</td>
<td>0.8 × 0.8 cm(^2)</td>
<td>4 MV (250)</td>
<td>6 MV (500)</td>
</tr>
<tr>
<td>Elekta</td>
<td>Amsterdam</td>
<td>in house(^c)</td>
<td>41 × 41 cm(^2)</td>
<td>1024 × 1024</td>
<td>20 × 20 cm(^2)</td>
<td>160 cm</td>
<td>0.8 × 0.8 cm(^2)</td>
<td>8 MV (200)</td>
<td>8 MV (400)</td>
</tr>
<tr>
<td>Varian A</td>
<td>Netherlands</td>
<td>iView aS500</td>
<td>40 × 30 cm(^2)</td>
<td>512 × 384</td>
<td>10 × 10 cm(^2)</td>
<td>145 cm</td>
<td>1.6 × 1.6 cm(^2)</td>
<td>6 MV (300)</td>
<td>6 MV (500)</td>
</tr>
<tr>
<td>Varian B</td>
<td>Rigshospitalet</td>
<td>PortalVision v6.1.03</td>
<td>40 × 30 cm(^2)</td>
<td>512 × 384</td>
<td>10 × 10 cm(^2)</td>
<td>145 cm</td>
<td>1.6 × 1.6 cm(^2)</td>
<td>6 MV (300)</td>
<td>10 MV (500)</td>
</tr>
<tr>
<td>Siemens A</td>
<td>Royal Marsden</td>
<td>PortalVision v6.1.11</td>
<td>41 × 41 cm(^2)</td>
<td>512 × 512</td>
<td>10 × 10 cm(^2)</td>
<td>150 cm</td>
<td>0.5 × 0.5 cm(^2)</td>
<td>6 MV (300)</td>
<td>6 MV (50)</td>
</tr>
<tr>
<td>Siemens B</td>
<td>University Hospital</td>
<td>PortalVision v6.1.11</td>
<td>41 × 41 cm(^2)</td>
<td>512 × 512</td>
<td>10 × 10 cm(^2)</td>
<td>150 cm</td>
<td>0.5 × 0.5 cm(^2)</td>
<td>6 MV (50)</td>
<td>10 MV (50)</td>
</tr>
</tbody>
</table>

The in-house software used with the Elekta EPIDs is very similar to the commercially available acquisition software provided by Elekta for the iView-GT detector.

Varian EPID, which has a different scintillator from the Elekta and Siemens detectors. The EPID signal for these studies was measured over different dose ranges, energies, and dose-rate settings compared to measurements with the Elekta EPIDs. Dosimetric characteristics for the Siemens EPIDs have not yet been reported. Non-linearity due to energy spectrum and dose/frame changes, or differences in acquisition software, can also influence the dosimetric characteristics.\(^{1,2,5,13}\) The purpose of this study was to compare the signal-to-monitor unit (MU) ratio for a comparable (wide) dose range, for all three \( \alpha\)-Si EPID brands.

II. MATERIAL AND METHODS

Six \( \alpha\)-Si EPIDs were investigated in this study: two Elekta panels (iView GT) from the Netherlands Cancer Institute, Amsterdam, The Netherlands, one Varian panel (aS500) at the Rigshospitalet, Copenhagen, Denmark, another Varian panel (aS500) at The Royal Marsden Hospital, London, United Kingdom, and two Siemens panels (OptiVue 500 and 1000) at the Maastricht University Hospital, Maastricht, The Netherlands. Commercial acquisition software was used to acquire images for the Varian and Siemens EPIDs. In-house software, on the other hand, was used to acquire images with the Elekta EPIDs. This software is very similar to the commercially available acquisition software provided by Elekta for the iView-GT detector.\(^{14}\) The active detection areas and image resolutions of each panel are given in Table I. The Varian aS1000 was not tested in this study, the difference between this panel and the aS500 is a higher resolution (1024 × 768 pixels), with the same active area and acquisition software.

Ghosting effects are known to depend on exposure time,\(^{5}\) which is linked to the dose-rate for a given dose. The Elekta and Siemens frame acquisition rates are constant, both \(~3.5\) frames per second (fps). The Varian acquisition rate depends on the linac pulse rate, which was \(~4.5\) to \(7.5\) fps for the dose-rates measured in this study. One of the differences between the two Varian panels tested in this study was that different versions of Varian’s PortalVision software were used to acquire images. The earlier version (v6.1.03, “Varian A”) employs a reset every 64 frames to move the frame buffer content to the CPU, creating a dead time of 0.28 s, or loss of one to two image frames (depending on the frame rate).\(^{10}\) More recent versions of the software do not have this dead time.

For each panel, images were acquired for a series of open square fields, irradiated with 5, 10, 20, 50, 100, 200, 500, and 1000 MUs, integrated over all frames. Various dose-rate and photon beam energies settings were tested, according to the available settings for each linac on which the panels were mounted. For the Elekta and Varian detectors, eight series were measured (A and B EPIDs, each with two dose-rate/beam energy combinations, each series measured twice). For the Siemens detectors, six series were included. “Siemens A” was measured with two dose-rate/beam energy combinations, and “Siemens B” with four dose-rate/beam energy combinations. Details regarding panel properties, beam pa-
Parameters, and image acquisition parameters are summarized in Table I. Measurements with the Elekta panel were performed first, with field size $20 \times 20 \text{ cm}^2$ and source-detector distance (SDD) = 160 cm. Measurements with subsequent detectors could not be made with the same parameters because the dimensions of the panels and the SDDs (and hence effective field size at the detector) varied at other clinics. All fields were much larger than the central region of interest (ROI) selected for analysis (by more than a factor of 8), to avoid any field edge effects. The results were expressed as the EPID signal divided by the number of MUs and then normalized to the ratio at 1000 MUs. It should be noted that only individual, non-segmented square fields were investigated to be able to compare the EPIDs without introducing too many variables. The implications of ghosting effects for IMRT fields (segmented or dynamic) fall outside the objectives of this study.

III. RESULTS

Figure 1 shows an average of the series measured for each of the three $\alpha$-Si EPID brands. For the Varian EPID, only four series using “Varian B” were included in the average (two dose-rate/beam energy combinations, each series measured twice). The measurements with “Varian A” were not included here because it uses a different acquisition software, however it is presented separately. All series exhibited a lower signal-to-MU ratio for shorter irradiation times. This is consistent with previous reports suggesting that ghosting effects depend on exposure and/or acquisition time.\textsuperscript{1,5} For irradiations of more than 200 MUs, the ratio for each detector was constant to within $\pm 1.5\%$, i.e., the response is effectively linear with dose. Below 200 MUs, the average signal-to-MU ratio decreases 4% for the Elekta panels, and 5% for the Varian and Siemens panels.

Error bars represent $\pm 1$ standard deviation (SD). The relative average SD was 0.3% and the maximum was $\pm 1.4\%$. As expected, the results averaged over the largest range of dose-rate/beam energy combinations had the largest SD, i.e., the Siemens dose-rate settings, ranging from 50 to 500 MU/min, with beam energies of 6 and 10 MV. A variation in the signal-to-MU ratio could be due to variation in the design and manufacture of the $\alpha$-Si layer, as used by Varian A, or read-out of the electronics, leading to a different number of charge particles trapped and/or read out in the bulk modulus or interface of the photodiode layer. In addition to physical differences, different image acquisition parameters (e.g., trigger levels) will also influence the EPID signal differently at various exposure times.

Signal-to-MU ratios measured at different beam energies and dose-rate settings for each detector are also shown in Fig. 2. For each detector type, the MU dependence was similar (within $\pm 1.4\%$) for all energies and dose-rate settings, except below 10 MUs for the Varian A and B EPIDs.

For the EPID using the earlier version of PortalVision (Varian A), the signal-to-MU curve dropped by 1% between 50 MUs (43 frames) and 100 MUs (95 frames), for both dose-rates. The discontinuity in the curve was due to the reset occurring every 64 frames and so resulted in a dead time during acquisition if more than 64 frames were acquired (Fig. 2). The data for both Varian A series were subsequently corrected for the missing signal due to dead time and are also given in Fig. 2. The difference in signal ratio between 5 and 1000 MUs is clearly much greater for the corrected Varian A than Varian B. The reason was not investigated further for this study, however it can be assumed that differences in image acquisition, panel design, and variation in read-out electronics are possible reasons for the differences between the two sets of measurements in Fig. 2.

Due to non-linearity of linac monitor signal, the Siemens EPID signals measured with 5 MUs, 6 MV, and 300 MU/min were corrected based on relative dose values measured with an ionization chamber. The linac output used for all other series was also checked and found to be linear, so no corrections were necessary. Two series were also measured with the “Siemens B” EPID at very low dose-rate settings of 50 MU/min. The relative signal-to-MU ratio at smaller number of MUs (0.96 at 5 MUs) was not as low as for the higher dose-rate settings (0.93 at 5 MUs, same EPID, same beam energies). This dose-rate dependence is consistent with ghosting behavior. Since ghosting depends on the exposure time and not on dose, slower dose-rates will result in an EPID signal with a much weaker MU dependence. This is because a lower nominal dose-rate setting at the linac will result in a lower dose per frame rate. At lower dose per frame rates, an equilibrium can be achieved much faster between the amount of charge that is trapped, and the amount that is read out. So at very low dose-rates, there would be no ghost-
manufacturer. This dependence indicated that charge trapping, resulting in ghosting effects, influences the a-Si EPID response to dose. Therefore it is important to be aware of the resulting relative under-response at shorter irradiation times. The similarity of the results for all detectors tested suggested that the acquisition time dependence, or ghosting effect, is a fundamental property of indirect detection a-Si-based EPIDs. The small differences between the signal-to-MU ratio for the three manufacturers was likely to be due to differences in panel design and acquisition software. Variation between curves of the same manufacturer may be due to a combination of dose-rate and energy dependence, both influencing the dose delivered per frame. Errors of 4–10% at the center of the field are likely to influence EPID dosimetry measurements if the imager is applied over a wide range of irradiation times, by varying dose or dose-rate, to single fields without corrections.

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Fig. 2. EPID signal-to-MU ratios, separated for Elekta, Varian, and Siemens detectors. Two panels (A and B) for each brand were tested and normalized at 1000 MUs. The curves are similar for all but one series. For the EPID using the earlier version of PortalVision (Varian A, “x”), there is a 1% “drop” in the curve, between 50 and 100 MUs, for both dose-rates. This discontinuity is due to a dead time introduced while frames are being stored, occurring every 64 frames. The data for both Varian A series are also presented, correcting for the missing signal (“*”).

The range of dose-rate settings for the Elekta and Varian panels was not large enough to see this effect. It should be noted that although all measurements were normalized to the respective EPID signals at 1000 MUs, there was variation in the EPID signal at this normalization point for different dose-rates of the order of a few percent (for the same detector brand, linac, and energy). This difference could be best illustrated with additional data at multiple dose-rate settings for each detector, linac, and energy combination, however this is beyond the scope of this technical note.

IV. CONCLUSIONS

Signal-to-MU ratios for all EPIDs tested showed a dependence on the number of MUs delivered, independent of the