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ORIGINAL ARTICLE

Comparative performance evaluation of a new a-Si EPID that exceeds quad high-definition resolution

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Summary

Purpose: *Electronic portal imaging devices (EPIDs) are an integral part of the radiation oncology workflow for treatment setup verification. Several commercial EPID implementations are currently available, each with varying capabilities. To standardize performance evaluation, Task Group Report 58 (TG-58) and TG-142 outline specific image quality metrics to be measured. A LinaTech Image Viewing System (IVS), with the highest commercially available pixel matrix (2688x2688 pixels), was independently evaluated and compared to an Elekta iViewGT (1024x1024 pixels) and a Varian aSi-1000 (1024x768 pixels) using a PTW EPID QC Phantom.*

Methods: *The IVS, iViewGT, and aSi-1000 were each used to acquire 20 images of the PTW QC Phantom. The QC phantom was placed on the couch and aligned at isocenter. The images were exported and analyzed using the epidSoft image quality assurance (QA) software. The reported metrics were signal linearity, isotropy of signal linearity, signal-to-noise ratio (SNR), low contrast resolution, and high-contrast resolution. These values were compared between the three EPID solutions.*

Results: *Computed metrics demonstrated comparable results between the EPID solutions with the IVS outperforming the aSi-1000 and iViewGT in the low and high-contrast resolution analysis.*

Conclusion: *The performance of three commercial EPID solutions have been quantified, evaluated, and compared using results from the PTW QC Phantom. The IVS outperformed the other panels in low and high-contrast resolution, but to fully realize the benefits of the IVS, the selection of the monitor on which to view the high-resolution images is important to prevent down sampling and visual of resolution.*

Key words: *EPID, High resolution, Image QA, LinaTech*

Introduction

EPIDs are an integral part of the daily workflow in a radiation oncology clinic to verify that patients are set up in a correct and consistent manner. EPID images are used for treatment setup verification by comparing against digitally reconstructed radiographs (DRR) from the patient's planning CT. Additional applications of EPIDs most recently include dose verification for intensity modulated radiotherapy QA, multileaf collimator QA, localization of implantable markers, and absolute dosimetry. Since clinics rely heavily on EPIDs, they must be checked regularly to ensure consistent image quality to meet the demands of the modern uses [1].

TG-58 outlines a set of important quantities including contrast, SNR, spatial resolution, and x-ray scatter that users of EPIDs should consider as measures of image quality [2]. Per TG-58, it is im-

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portant to perform constancy checks of SNR, resolution, and localization monthly to assess image quality. TG-142 also recommends that the scaling, spatial resolution, contrast, uniformity/noise, and imaging and treatment coordinate coincidence be checked [3].

Commercial phantoms and software tools exist to assist physicists with performing these tasks by streamlining the process to test consistency in the EPIDs. These QA phantoms focus on testing the monthly check parameters outlined in TG-58 and TG-142 and comparing the monthly measurements to a baseline set. When evaluating a new EPID, it is sensible to compare its performance to existing technologies by using an established QA phantom. Das et al. evaluated the PTW EPID QC Phantom with epidSoft software across multiple clinical EPID platforms and found that the phantom provided a simple to use tool that analyzed basic and advanced imaging parameters [1].

In this study, a LinaTech IVS performance was compared against an Elekta iViewGT and a Varian aSi-1000 using the PTW QC Phantom to acquire a standard set of image quality metrics across all the EPID technologies. The goal of this study was to characterize and evaluate the performance of the IVS, which is the highest resolution panel in the market, against other commercially available EPID solutions using a standard EPID QA system.

Methods

EPID Technology

Three EPID technologies were utilized in this study: the IVS (LinaTech, Sunnyvale, CA), the iViewGT (Elekta, Crawley, UK), and the aSi-1000 (Varian, Palo Alto, CA). All three of these systems are designed with amorphous silicon (a-Si) detector panels.

The physical dimensions of the three panels are different. The IVS uses an FP142 flat panel a-Si detector, which has a sensitive area of 41×41 cm^2 with the highest commercially available pixel matrix of 2688×2688 and a pixel size of 0.15 mm [4]. This resolution exceeds the Quad High-Definition display standard of 2560×1440 resolution (3.7 million pixels), but with a total pixel count of 7.2 million pixels, the IVS is closer to the pixel count of a 4K display (8.3 million pixels). The iViewGT uses a PerkinElmer XRD1640 AL5 amorphous silicon panel (PerkinElmer Optoelectronics, Fremont, CA, USA) [5]. Its sensitive area is equal to the IVS panel at 41×41 cm^2; however, it has a smaller pixel matrix of 1024×1024, resulting in larger pixel size of 0.4 mm [6,7]. The aSi-1000 panel differs from the other panels with a sensitive area of 40×30 cm^2 and the smallest pixel matrix of 1024×768, resulting in a 0.39 mm pixel size [8]. While the physical areas of the iViewGT and the aSi-1000 differ, the resulting pixel size is very similar. When compared with the IVS though, their pixel sizes are nearly three times as large as the IVS.

PTW EPID QC Phantom

The EPID QC Phantom is commercially available from PTW-Freiburg as a tool to check the consistency of the image quality of EPIDs using beams ranging from 4 to 25 MV [9]. The QC Phantom measures 250 mm×250 mm×42 mm. It is designed to be imaged with a source-to-surface distance (SSD) of 96.2 using a field size of 26×26 cm^2 to completely cover all test elements of the phantom [9]. The phantom consists of five groupings of test elements designed to check: 1) signal linearity and SNR, 2) isotropy of signal linearity, 3) geometric isotropy (distortion), 4) low contrast resolution, and 5) high contrast resolution [1].

The accompanying PTW software to the QC Phantom, epidSoft, was used to analyze all the images. To test signal linearity, a set of 10 copper wedges representing 0%, 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, and 50% absorption rate for a 6MV beam were used. The mean of the gray value of each copper step output was used to calculate the linearity curve. The mean of the gray value of each copper step output was divided by the standard deviation (noise) for each step to calculate SNR.

To test isotropy of signal linearity, 6 blocks of 4 brass steps covering 10%, 20%, 30%, and 40% for a 6MV beam were used to calculate the mean gray values associated with them. These values were then used to calculate a regression line. The original mean gray values were used to determine the maximum deviation from the regression line.

To test for low contrast resolution, a set of 27 holes of 5 different depths and 6 different diameters were used. The depths ranged from 0.5 to 4.8 mm, while the diameters ranged from 1.1. to 15 mm. To quantify low contrast resolution, the contrast between each hole and a specified area around the hole were calculated.

To test for high-contrast resolution, 14 blocks of line pair patterns with 18 resolutions ranging from 0.125 lp/mm to 3.3 lp/mm were used. They were used to calculate the modulation transfer function (MTF) by calculating the mean value of the maxima (lamellae) and the mean value of the minima (gaps) in the line pair pattern. Lastly, the calculated MTF values were normalized to the smallest available spatial frequency to obtain a relative MTF.

Image Quality Check

The PTW EPID QC Phantom was used to evaluate image quality metrics on the IVS, iViewGT, and aSi-1000 technologies. The systems were paired with linear accelerator systems as follows: IVS with a Varian 23EX, iViewGT with an Elekta VersaHD, and aSi-1000 with a Novalis Tx. The phantom was placed on the respective couch in each treatment room and aligned to isocenter at the base using the lines on the side of the phantom.

The field size used was 26×26 cm^2 for the Elekta iViewGT as well as the LinaTech IVS and 25×25 cm^2 for the Varian aSi-1000. All images were acquired using a 6MV beam with the optimal exposures and dose rates per manufacturer guidelines. Exposures of 2 MU (iViewGT), 4 MU (aSi-1000), and 1 MU (IVS) were delivered to the panels. Twenty images were taken in succession on the respective EPIDs without removal from the table between acquisitions to eliminate setup variations.

Results

EPID Images

Figures 1 through 3 show representative images from each EPID panel in this study. To comparatively view the images from all three panels shown in the Figures, exported DICOM images were post-processed to remove data falling outside of 98% of the intensity distribution. This was not performed for the image quality analysis in epidSoft, but only for the display of images shown here to provide an unbiased contrasting technique to improve presentation quality without introducing imbalances caused by user based window-leveling. Since the physical dimensions of the IVS and the iViewGT are the same (41×41 cm^2) and are square, the image shown is also square. Since the width and height are not the same for the aSi-1000, the entire captured image is shown and contains empty regions.

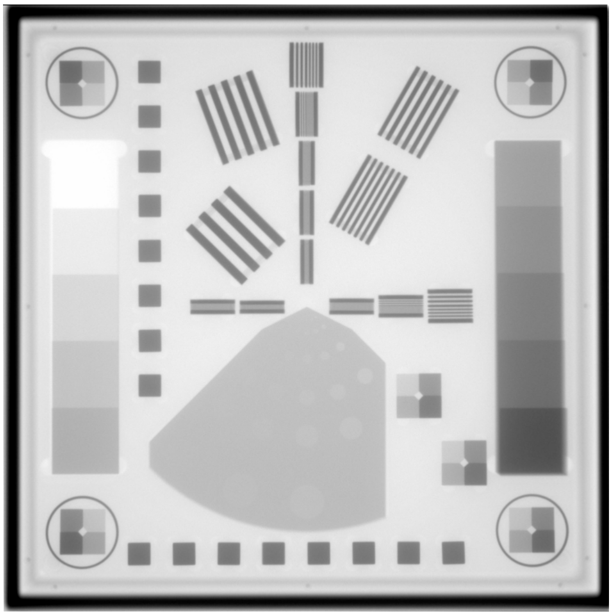

Figure 1. Image of QC phantom captured with the LinaTech IVS EPID.

Image Quality Metrics

epidSoft analysis was compiled, averaged, and the results are shown in Figure 4A-F. Figure 4A shows the average signal linearity. Figure 4B shows the local dependence of linearity data reported from the 'top left' set of blocks; there was minor variation between each set of blocks. Figure 4C shows the average SNR ratio. The zero-absorption data point for the IVS was removed because it was reporting extremely high values indicating an overexposure per the software guidelines. The software guidelines recommended lowering the dose; however, for the IVS the lowest deliverable value of 1 MU was already being used to capture the image. Figure 4D shows the average low contrast resolution results given in relative percent difference between the specific borehole and the background. Figure 4E and 4F show the high-contrast resolution results in the form of MTF (4E: Vertical MTF; 4F: Horizontal MTF).

Table 1 shows the average maximum deviation from the regression line for signal linearity and local dependence of linearity.

Table 2 lists the borehole diameter and depth dimensions associated with the low contrast resolution test.

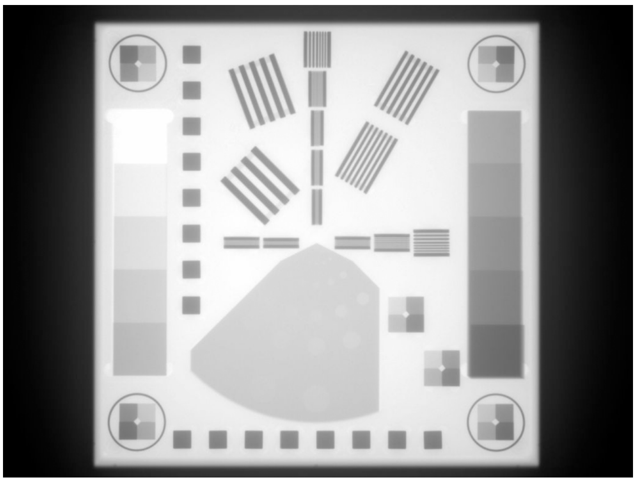

Figure 2. Image of QC phantom captured with the Varian aSi-1000 EPID.

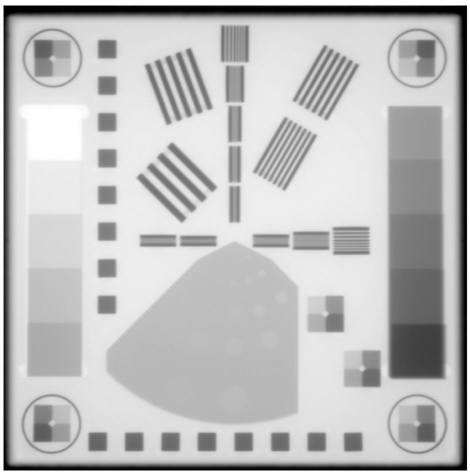

Figure 3. Image of QC phantom taken with the Elekta iViewGT EPID.

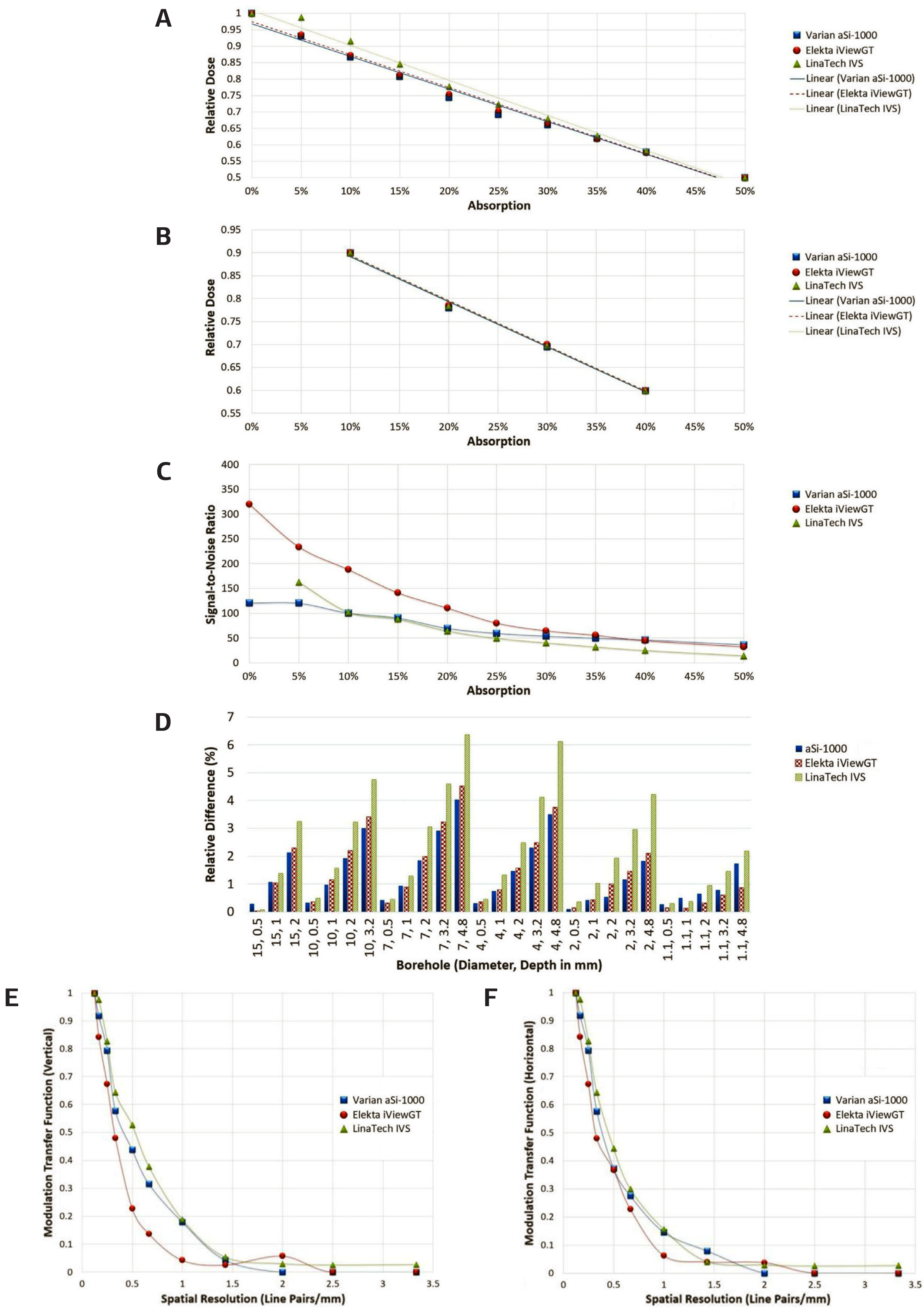

Figure 4. Results of epidSoft analysis by imager. **A:** Linearity of copper step wedges graphed against individually calculated regression line. **B:** Top left local dependence of linearity graphed against individually calculated regression line. **C:** Average signal-to-noise ratio. **D:** Average low contrast resolution values (x-axis lists 'borehole diameter, depth' in mm). **E:** Vertical MTF. **F:** Horizontal MTF.

Table 1. Average maximum deviation from calculated regression line for signal linearity and local dependence of linearity for each imaging panel

	LinaTech FP142a	*Varian aSi-1000*	*Elekta iViewGT*
Signal Linearity Avg Max Deviation from Regression Line	0.049±0.025	0.05±0.188	0.048±0.018
Local Dependence of Linearity Avg Max Deviation from Regression Line	0.019±0.014	0.021±0.089	0.016±0.033

Table 2. Relative percent difference of holes from background for three EPID solutions as measured by the PTW QC Phantom

Borehole	*Diameter (mm)*	*Depth (mm)*	*aSi-1000*	*IVS*	*iviewGT*
				Relative difference (%)	
L0	15	0.5	0.29	0.07	0.03
L1	15	1	1.06	1.38	1.04
L2	15	2	2.14	3.25	2.30
L3	10	0.5	0.32	0.49	0.35
L4	10	1	0.98	1.57	1.15
L5	10	2	1.93	3.23	2.20
L6	10	3.2	3.01	4.75	3.41
L7	7	0.5	0.43	0.44	0.32
L8	7	1	0.94	1.29	0.88
L9	7	2	1.86	3.06	1.99
L10	7	3.2	2.91	4.60	3.23
L11	7	4.8	4.03	6.36	4.52
L12	4	0.5	0.31	0.44	0.36
L13	4	1	0.75	1.32	0.79
L14	4	2	1.47	2.50	1.56
L15	4	3.2	2.31	4.12	2.48
L16	4	4.8	3.51	6.11	3.75
L17	2	0.5	0.10	0.35	0.14
L18	2	1	0.43	1.02	0.43
L19	2	2	0.54	1.94	0.99
L20	2	3.2	1.17	2.95	1.46
L21	2	4.8	1.82	4.22	2.11
L22	1.1	0.5	0.27	0.31	0.14
L23	1.1	1	0.50	0.37	0.13
L24	1.1	2	0.64	0.95	0.31
L25	1.1	3.2	0.79	1.47	0.61
L26	1.1	4.8	1.74	2.18	0.88
Average			1.34	2.25	1.39

Discussion

The measurement of signal linearity showed similar responses between the EPIDs, with the IVS data visually appearing slightly more nonlinear in the initial low absorption region than the other imagers. However, the linear regression line shows the IVS performing linearly, which is reiterated by the calculated maximum deviations from the linear regression line in Table 1. The maximum deviations are shown to be consistent between imaging panels indicating no alarming deviations in linearity between panels.

The local dependence of linearity also showed that there was no alarming linear dependence based on position on the individual panels. The maximum deviations were consistent across the panels, indicating the panels performed similarly in this test.

The SNR analysis showed more spread between panels, with the iViewGT reporting the highest SNR values in the low absorption regions. In the higher absorption regions, the SNR was less spread out, and the IVS panel showed the lowest SNR, while the aSi-1000 and the iViewGT chart on top of each other. A limit of this metric is that the images were taken using the clinical recommendations for each panel, so the number of MU was not consistent across all panels. This means that the total number of photons used to make the image was also not consistent. Since noise is inversely proportional to the number of photons, in the case of higher MU, the noise would be lower [10]. If the noise was lower, given the same signal, this could manifest as a higher SNR value, thus these should be interpreted with caution.

The low contrast resolution analysis showed the IVS reporting the greatest relative percent difference from background on all boreholes as compared to the iViewGT and all boreholes except L1 and L23 as compared to the aSi-1000. On average the IVS relative percent differences from background were 1.62 times greater than the iViewGT and 1.68 times greater than the aSi-1000. The maximum ratio between relative percent differences was 3.05 for the iViewGT (borehole L24) compared to the IVS and 3.58 for the aSi-1000 (borehole L19). The minimum ratio was 1.24 for the iViewGT (borehole L12) and 0.24 for the aSi-1000 (borehole L1).

The high-contrast resolution analysis showed that the IVS produced higher MTF at the higher spatial frequencies, in both the horizontal and vertical directions, than the other panels. The IVS MTF and the aSi-1000 MTF tracked the best with each other, while the iViewGT consistently showed lower MTF values. In the region of higher spatial frequencies, the MTF values sometimes appear to increase and decrease. The way the algorithm performs the analysis can be responsible for this by latching onto variations in noise in the region rather than true detectability of the lamellae and gap regions.

In terms of subjective evaluation of image quality, we expected to see visual differences between the image quality of the different panels. This was expected since the IVS has about 60% smaller pixels. Pixel density, commonly referred to pixels per square inch (PPI), is a useful metric when evaluating display-based technologies since it provides a standardized value that considers both number of pixels and physical size of the detector. A general formula for calculating PPI is taking the diagonal resolution (pixels) and dividing it by the diagonal panel size (inches). The PPI of the three panels in this study are calculated as:

$$PPI_{IVS}=\frac{\sqrt{2688^2 pixels+2688^2 pixels}}{\sqrt{41^2 cm+41^2 cm}*\frac{1in}{2.54cm}}=\frac{3801.41 pixels}{22.83 inch}\approx 166.51 PPI$$

$$PPI_{iViewGT}=\frac{\sqrt{1024^2 pixels+1024^2 pixels}}{\sqrt{41^2 cm+41^2 cm}*\frac{1in}{2.54cm}}=\frac{1448.15 pixels}{22.83 inch}\approx 63.43 PPI$$

$$PPI_{aSi\text{-}1000}=\frac{\sqrt{1024^2 pixels+768^2 pixels}}{\sqrt{40^2 cm+30^2 cm}*\frac{1in}{2.54cm}}=\frac{1280 pixels}{19.68 inch}\approx 65.07 PPI$$

Comparing the PPI of the panels, the IVS has 166.51 PPI, the iViewGT has 63.43 PPI and the aSi-1000 has 65.07 PPI. The iViewGT and aSi-1000 report very close PPI values, despite the aSi-1000 having lower resolution than the Elekta iViewGT. The IVS has about 2.5 times more PPI than both the iViewGT and the aSi-1000.

When viewing the images captured by these devices, it is important to consider the monitor on which the image is being viewed. Depending on the native resolution of the monitor, the image may appear better or worse. If the monitor has a lower PPI than the image, the image will be down sampled to be graphically represented by a smaller number of pixels, which will result in degradation of image quality. In the case of the new high-resolution imaging panels, like the IVS, care must be taken when selecting a monitor on which to view these images. A target PPI for a monitor when viewing images from the IVS panel would be a PPI greater than 100, optimally closer to 166 PPI. Exceeding 166 PPI will not enhance image quality. A few configurations for monitors that are standard to industry that achieve above 100 PPI are: 19" with 1950×1080 resolution (116 PPI), 25" monitor with 2560×1440 resolution (117 PPI), and 27" with 3840×2160 resolution (163 PPI). The combination of screen size and resolution ultimately drives how the image will be viewed; bigger monitors are not always better if the resolution does not scale accordingly.

In addition to monitor PPI concerns, the type of materials used in the display of the monitor can influence the subjective image quality [11]. Monitors are used to be predominantly based on cathode ray tube (CRT) technology; however, it is more common to find liquid crystal displays (LCD) in clinics today. There are several types of LCD panels currently available such as twisted nematic (TN), vertical alignment (VA), and in-plane switching (IPS). TN panels are more affordable than the other two types of LCD monitors but are inferior at color reproduction. They also tend to have the most restricted viewing angles. When using a TN panel, depending on the viewing angle, the contrast-ratio changes. This means that two individuals sitting side by side at a monitor could be seeing two different image qualities. VA panels offer higher contrast ratios when compared to TN panels, which leads to better black levels and have better viewing angles. IPS panels are generally considered the best LCD technology with the best color production and viewing angles; however, they are generally more expensive.

Lastly, monitor calibration can be an issue from one display to another when assessing the quality of images produced by an EPID. Gamma calibration affects the relationship between individual pixels and their brightness. Color temperature affects the way white is viewed on a monitor. To maintain representation of an image from one display to another, displays can be calibrated to a determined baseline such that all viewers will have consistent image representation regardless of which device is used. This can be achieved by using a colorimeter and software with consistency in settings when calibrating displays [12].

In addition to image quality, there is a dosimetric difference in performance between the panels since the IVS requires less radiation (1 MU) delivered per image compared to the aSi-1000 (4 MU) and iViewGT (2 MU). The effect will be greater for treatment schedules where more EPID images are required. Although there is no standard way of incorporating the additional dose delivered to a patient when using ionizing-radiation-based image guidance systems, the quantification of additional dose delivered to patients has been the focus of studies [13,14].

Conclusion

Overall, the image quality performance evaluation showed comparable results between the IVS, iViewGT, and aSi-1000. However, the IVS showed greater low and high-contrast resolution than the other imaging panels. The selection of a monitor to view these newer, high resolution images on is important to ensure that the added value of a higher resolution image is maintained.

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Conflict of interests

PTW provided the QC Phantom used in this study.

References

1. Das I, Cao M, Cheng C-W et al. A quality assurance phantom for electronic portal imaging devices. J Appl Clin Med Phys. 2011;12:391-403.
2. Herman MG, Balter JM, Jaffray DA et al. Clinical use of electronic portal imaging: Report of AAPM Radiation Therapy Committee Task Group 58. Med Phys 2001;28:712-37. doi:10.1118/1.1368128.
3. Klein EE, Hanley J, Bayouth J et al. Task Group 142 report: Quality assurance of medical acceleratorsa): Task Group 142 Report: QA of Medical Accelerators. Med Phys 2009;36:4197-4212.
4. LinaTech. TiGRT Image Viewing System Overview.
5. Winkler P, Georg D. An intercomparison of 11 amorphous silicon EPIDs of the same type: implications for portal dosimetry. Phys Med Biol 2006;51:4189-4200.
6. Perkin E. XRD a-Si Detector Overview and Nomenclature. http://www.perkinelmer.com/PDFs/downloads/SPC_FPDOptionsOverview.pdf.
7. Hosier K, Wu C, Beck K et al. SU-E-T-164: Clinical Implementation of ASi EPID Panels for QA of IMRT/VMAT Plans. Med Phys 2012;39:3740-1.
8. Mekuria Y, Bjorkqvist M, Kulmala J. Quality Control and Pre-Treatment Quality Assurance Application of EPID (aS1000) for FF and FFF Beam VMAT Plans. Med Phys Int 2015;3:1336-73.
9. User Manual - EPID QC Phantom and epidSoft Software.
10. Bushberg JT (Ed): The Essential Physics of Medical Imaging (3rd Edn). Philadelphia: Wolters Kluwer Health/Lippincott Williams & Wilkins; 2012.
11. Kagadis GC, Walz-Flannigan A, Krupinski EA et al. Medical Imaging Displays and Their Use in Image Interpretation. RadioGraphics 2013;33:275-90.
12. Samei E, Badano A, Chakraborty D et al. Assessment of display performance for medical imaging systems: Executive summary of AAPM TG18 report: Performance assessment of medical displays. Med Phys 2005;32:1205-25.
13. Murphy MJ, Balter J, Balter S et al. The management of imaging dose during image-guided radiotherapy: Report of the AAPM Task Group 75: Imaging dose during image-guided radiotherapy. Med Phys 2007;34:4041-63.
14. Gupta T, Narayan CA. Image-guided radiation therapy: Physician's perspectives. J Med Phys 2012;37:174.