The use of computed radiography plates to determine light and radiation field coincidence

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Purpose: Photo-stimulable phosphor computed radiography (CR) has characteristics that allow the output to be manipulated by both radiation and optical light. The authors have developed a method that uses these characteristics to carry out radiation field and light field coincidence quality assurance on linear accelerators.

Methods: CR detectors from Kodak were used outside their cassettes to measure both radiation and light field edges from a Varian linear accelerator. The CR detector was first exposed to a radiation field and then to a slightly smaller light field. The light impinged on the detector's latent image, removing to an extent the portion exposed to the light field. The detector was then digitally scanned. A MATLAB-based algorithm was developed to automatically analyze the images and determine the edges of the light and radiation fields, the vector between the field centers, and the crosshair center. Radiographic film was also used as a control to confirm the radiation field size.

Results: Analysis showed a high degree of repeatability with the proposed method. Results between the proposed method and radiographic film showed excellent agreement of the radiation field. The effect of varying monitor units and light exposure time was tested and found to be very small. Radiation and light field sizes were determined with an uncertainty of less than 1 mm, and light and crosshair centers were determined within 0.1 mm.

Conclusions: A new method was developed to digitally determine the radiation and light field size using CR photo-stimulable phosphor plates. The method is quick and reproducible, allowing for the streamlined and robust assessment of light and radiation field coincidence, with no observer interpretation needed. © 2013 American Association of Physicists in Medicine. [<http://dx.doi.org/10.1118/1.4823775>]

Key words: computed radiography, linac QA, light radiation coincidence, crosshair

1. INTRODUCTION

Light and radiation field coincidence has long been a quality assurance (QA) measure for linear accelerators. Because the light and radiation sources are two independent components, each can change with respect to the other, necessitating constancy checks. TG-142 (Ref. 1) recommends that the coincidence between these two components be within 2 mm/1% per side for symmetric field sizes. Both patient localization and physics QA involve the use of the light field and crosshair and the accuracy of each is extremely important.

Daily, monthly, and annual QA tests that involve precise setups very often use the light field and crosshair as alignment surrogates. Classic tests for this usually involve irradiating a film, marking the light field size with external marks, and then comparing the markings with the radiation field. This method, although common, is largely unreliable.² Methods developed to improve upon this test usually involve either a custom jig or commercial devices.^{3–9} Custom jigs can potentially be very accurate but largely depend on the user for initial setup or

interpretation of the light field and require the ability to build or pay for the jig as well as ensure its integrity over time. Devices such as two-dimensional arrays are only surrogates for light-radiation field coincidence, and although they are precise, they can be inaccurate. Compared to classic tests, the precision of light and radiation field coincidence using these devices can be improved considerably, but interpretation of the results and verification of accuracy is necessary, which introduces intra- and interobserver variation that limits the accuracy of some of these methods.

The method presented here is advantageous for several reasons. First, it does not rely on the observer for interpretation of either the radiation or the light field, which increases its theoretical accuracy. Second, it directly measures the light field, as opposed to surrogates, as most other techniques do. Third, it does not require a custom or commercial jig; it is inexpensive and can be performed quickly in any clinic with a computed radiography (CR) system already commissioned. Fourth, unlike other light-radiation field coincidence methods, our technique also captures the crosshair location, which gives the physicist more information about the

crosshair's interplay with the light field, radiation field, and jaws.

2. METHODS AND MATERIALS

2.A. Detector, setup, and irradiation

A CR detector (ACR-2000i) from Kodak (Rochester, NY) was used for the measurements. The detector contains a photo-stimulable phosphor plate that is normally set within a case. The case provides a copper plate for filtering and build up, physical protection of the plate, and protection from optical light. All of these are usually desired for standard usage, but for this study, we sought to take advantage of the detector's light sensitivity, so the detector was taken out of its case prior to irradiation. Because this method utilizes the light field removing the latent image after irradiation, it is necessary that the latent image, i.e., the radiation field, always be larger than the light field, otherwise if the light field is larger then no information could be acquired. This necessitated always using a light field smaller than the radiation field.

Irradiations of the CR plates were done on a Varian 21EX, all with the 6 MV photon beam. The CR plate was laid on the treatment couch at 100 cm SSD to provide some level of build-up. The detector was then taped to the couch, 1 cm of solid water was placed on top of the detector for build-up and the room lights dimmed to the lowest setting. To determine the jaw motion hysteresis and its effect on field size, two sets of data were acquired. The first set was acquired by setting the jaws to a large field size and then down to the size used for the irradiation and for the light field. The second set was the same process but field sizes were set after moving the jaws from a smaller field size. All sizes were set automatically by the linac console to both remove observer influence and determine what was happening clinically since for patient treatments the automatic movement is used.

The first data set followed this sequence (all values are in cm^2): 25×25 , 20×20 , irradiation, 25×25 , 18×18 , light exposure. The second data set was similar except a $10 \times 10 \text{ cm}^2$ field size was used instead of $25 \times 25 \text{ cm}^2$. Each data set was taken using two CR plates used twice each, resulting in four data points per data set. For all irradiations, 2 monitor units (MU) were delivered. After the irradiation, the solid water build up was removed and jaw size set as per the sequence of the data set, and the field light was turned on for 90 s. The CR plate was then removed, put into its cassette and taken to be processed at the digital CR reader. The reader digitized the image and created a DICOM file with the image and header information (including pixel-mm conversion factor). An example of such a readout is shown in Fig. 1.

Consistency of response across detectors was tested by repeating the experiment using two different CR detectors and comparing the results. Kodak extended dose range 2 (EDR2) film were irradiated to 200 cGy with a $20 \times 20 \text{ cm}^2$ field under the same conditions as the CR plate; two films were irradiated for each method mentioned above. The films were

FIG. 1. The resultant image of a computed radiography plate taken out of its cassette, irradiated with a $20 \times 20 \text{ cm}^2$ field at 100 cm, and then exposed to 90 s of the linear accelerator's light field at $18 \times 18 \text{ cm}^2$.

processed and then digitized with a VXR DosimetryPRO advantage film digitizer (Vidar Systems Corp., Hendon, VA). After this the images were analyzed to verify the radiation field size determined by the CR detector. Finally, values were compared to the previous week of results of the daily QA device (DailyQA3, Sun Nuclear Corp.) which records radiation field size and the central axis shift from nominal. Comparisons to previous monthly light-radiation field coincidence tests were not done as only qualitative evaluations were performed with film.

To ensure the integrity of the method, two additional tests were performed. The effect of field light exposure time on the latent image was tested by irradiating a detector and turning on the field light for 30 s. One of the Y-jaws was then closed 4.5 cm and the field light was again turned on for 30 s. This was repeated across the field to create an image showing the effects of 30, 60, 90, and 120 s of light exposure (Fig. 2).

To ensure the method was not saturating the CR plate, the effect of different MU on the CR pixel response was tested. A $20 \times 20 \text{ cm}^2$ field was set and the plate exposed to 1 MU. One of the Y-jaws was moved 4.5 cm inward, and 1 more MU given. This was repeated, with the addition of 1 MU each time, until there were four distinct regions of exposure between 1 and 4 MU. To minimize any effect of the light field on the left and right radiation edges, a $10 \times 18 \text{ cm}^2$ field was formed, and the plate was exposed to the light field for 90 s (Fig. 3).

FIG. 2. An image showing irradiation of $20 \times 20 \text{ cm}^2$, with the light field exposing parts of the field. A Y-jaw was moved down 4.5 cm every 30 s, creating four exposed sections with 30–120 s of light exposure from top to bottom.

FIG. 3. 1 MU was delivered at $20 \times 20 \text{ cm}^2$, after which a Y-jaw was moved up 4.5 cm, another MU was delivered, and so on, until four regions of 1–4 MU were created. A single light exposure of $10 \times 18 \text{ cm}^2$ for 90 s was used to ensure that the light did not affect the radiation field edges.

FIG. 4. (a) A raw profile of an image acquired with our technique. (b) The background subtraction and field edge determination. The slope of the radiation edge was fitted to a line and the pixel response outside the field was also fitted; the intersection of the lines was set as the radiation field minimum. For each field the 50% value point between the minimum of each side relative to the maximum was taken to be the respective field edge.

2.B. Analysis algorithm

We developed an algorithm in MATLAB (R2012b; The Mathworks, Natick, MA) to automatically analyze the CR images. The algorithm uses pixel intensity to determine the location of the full width at half maximum (FWHM) of the radiation field outline, light field outline, and field crosshair. A user-defined number of profiles can be used to determine the light and radiation field edge and crosshair FWHMs; for this study, 30 equidistant pixel profiles on each side were used. The profiles were then interpolated bicubically to gain subpixel precision and then analyzed.

The background signal must first be removed from the image before profile analysis can be done. A typical unaltered profile is shown in Fig. 4(a). The image is processed through a maximum gradient edge-finding technique, which coarsely corresponds to the 50% maximum radiation field point. The slope of the surrounding pixels is found and a line fitted. The pixel response just outside the radiation field is also linear and a line is fitted to it as well. The lines of the two data set slopes will intersect, and the point of intersection is taken to be the profile background value, the value of which is subtracted when calculating the radiation field edge. This technique is visualized in Fig. 4(b).

Figure 5 demonstrates a schematic of the field analysis. Each side of the remaining strip of radiation field is analyzed separately. To determine the edge of the light and radiation fields, the maximum intensity point of each profile was determined, followed by the minimum intensity point on either side of this maximum. Then, the 50% intensity points on each side of the profile were found. The outer 50% point was defined as the radiation field edge, and the inner 50% point as the light

FIG. 5. A schematic of what the algorithm analyzes in the image. In this drawing, four profiles are shown for display. The algorithm creates equidistant profiles on each side of the field (30 profiles in this study) and then finds the 50% intensity point on each side of the radiation line. On the inside of the inner schematic box, equidistant profiles of the crosshair are taken, and the center of the full width at half maximum is determined, representing the crosshair center.

edge, as shown in Fig. 4(b). For the crosshair, the average of the centers of the FWHMs of each profile in a respective direction was taken to be the crosshair center. However, linac mylar windows can often be contaminated by dried water or substance spots that sometimes give false values for the light field 50% point and crosshair, so a search of the points was done to identify any points outside a tolerance of a few pixels, and those points were removed from the calculation. The center of each field and the crosshair center were plotted in the X-Y coordinate plane, and their positions relative to each other were displayed.

3. RESULTS

The result of a typical irradiation sequence for this procedure is shown in Fig. 1. The image is automatically saved as a DICOM file by the CR reader and then imported into the MATLAB program to be analyzed. Postanalysis results are displayed graphically and in text by the program and are shown in Figs. 6 and 7.

A physical distance-to-pixel conversion ratio is given in the CR DICOM header. Because the plate was at 100 cm SSD, the nominal distance at which field size is defined, the ratio can be applied to the image and directly compared with nominal values.

FIG. 6. A fully analyzed image of the light-radiation technique presented here. Outer edge marks (green) and inner edge marks (red) depict the algorithm's results for the radiation and light field edges, respectively. Marks along the crosshair (blue) represent the center of the full width at half maximum of the crosshair.

FIG. 7. An enlarged view of the image showing the locations of the radiation and light field centers and crosshair center. Results are both displayed and listed quantitatively in our program.

TABLE I. Results using CR plates, EDR2 film, and a DailyQA3 device. The In→Out, Out→In methods are described in the text and refers to the procedure by which the field size was automatically made: from a smaller field size or a larger one. RF is the radiation field, LF is the light field, width Δ is the radiation field width minus the light field width minus 2 cm (the nominal difference of $20 \times 20 \text{ cm}^2$ vs $18 \times 18 \text{ cm}^2$), X→L is the distance from the crosshair location to the center of the light field, and X→R is the distance to the center of the radiation field. Positive values indicate being above or to the right; negative values indicate being below or to the left. Standard deviations in the determination are listed in parentheses.

Modality	Field side	Method	RF width (cm)	LF width (cm)	Width Δ (cm)	X→L (mm)	X→R (mm)
CR	X	In→Out	19.91(0.04)	17.88(0.05)	0.03	0.27	0.41
		Out→In	19.84(0.02)	17.83(0.02)	0.02	0.33	0.47
		Average	19.88(0.05)	17.85(0.05)	0.02	0.30	0.44
	Y	In→Out	20.06(0.02)	17.87(0.04)	0.18	−0.43	−0.54
		Out→In	19.94(0.02)	17.77(0.01)	0.16	−0.40	−0.54
		Average	20.00(0.06)	17.82(0.06)	0.17	−0.42	−0.54
Film	X	In→Out	19.91(0.02)				
		Out→In	19.93(0.03)				
		Average	19.92(0.02)		0.07		
	Y	In→Out	19.95(0.02)				
		Out→In	19.91(0.02)				
		Average	19.93(0.02)		0.11		
Daily device	X	Average	19.92(0.03)		0.07		0.28
	Y		19.92(0.02)		0.10		−0.22

Results from all data sets, including film, are listed in Table I. The difference between methods for the CR plates had up to 1.2 mm radiation field width difference and up to 1.0 mm light field width difference, both in the Y-direction. The In→Out method consistently resulted in larger field sizes than those of the Out→In direction, demonstrating that there seems to be hysteresis in the jaw movements in the initial direction of jaw travel, despite the automatic console control. These differences are slightly smaller for the light field, but still consistent. After accounting for the 2 cm nominal difference in field sizes, the overall light-radiation field coincidence is within 0.2 mm in the X-direction, while there is a notably large and consistent discrepancy between the light and radiation fields in the Y-direction of up to 1.8 mm. When comparing the average light field width results to those of the other modalities the width difference is at maximum 1.2 mm. The film results showed much less variation in radiation field size between methods than did the CR plates, with only 0.2 mm maximum deviation, which seems to nullify the CR demonstration of hysteresis. In comparing the CR and film results, the X-direction values were the same while the Y-direction values were slightly larger with the CR plates, with a difference of 0.6 mm. Finally, the results of the daily QA device were effectively the same as those of the film, with results within the range of uncertainty.

Analysis of the center-of-field was done for both light and radiation fields and related to the crosshair center, as between sequential experiments it was chosen as the most reproducible reference. For all CR data acquired, the radiation field center and light field center were plotted relative to the crosshair center, as shown in Fig. 8, and the values are listed in Table I. The results show that the procedure was consistent across irradiations. The 2D range of data for the light field centers was 0.32 mm, while for the radiation centers it was 0.39 mm. No

discernible pattern of the field centers was noticed between irradiation methods. The daily device center-of-field values assume that the device was set up perfectly with the field crosshair; values are listed in Table I and agree with the CR results to within approximately 0.3 mm.

The effects on radiation and light fields by varying the MU given to the CR plate and the light field exposure time are listed in Table II. Variation in radiation field width across 1–4 MU was 0.03 cm, and variation in light field width between the 30 s and 120 s exposure times was also 0.03 cm, demonstrating the consistency of the algorithm and robustness of experimental conditions on the results.

FIG. 8. A plot of the results showing the relative locations of the light and radiation field centers to that of the crosshair for eight experiments using the presented technique. Our program allows the user to choose which point to act as the reference. Between sequential experiments, the crosshair was thought to be most reproducible and thus was the point of reference for all experiments and plotted at the origin in all cases. X-displacement is in the water tank/klystron direction and the Y-displacement is in the gun/target direction.

TABLE II. The effects on radiation and light field width by varying the MU exposure and field light exposure. Standard deviations are listed in parentheses.

	Field width (cm)		
	MU effect		Light effect
1 MU	19.91 (0.01)	30s	17.85 (0.01)
2 MU	19.91 (0.01)	60s	17.86 (0.01)
3 MU	19.93 (0.01)	90s	17.87 (0.01)
4 MU	19.94 (0.01)	120s	17.88 (0.01)

4. DISCUSSION

The method of finding light and radiation field congruence described here is a simple test that a clinic can easily implement if a CR system has already been commissioned. Results show that the method is reproducible, with a standard deviation of less than 1 mm in the field widths and less than 0.1 mm for the relative positions of the light field center and crosshair center to the radiation field center.

The algorithm is fully automatic, which eliminates observer variation in the results. Because of the additional information acquired by our method, namely, the crosshair location, the algorithm can be modified to analyze individual jaw positions relative to the crosshair, rotation of the crosshair relative to the jaw angle, or rotation in the light field. The MATLAB program is packaged as a graphical user interface and is freely available from one of the authors (J.R.K.).

There was an inconsistency of the CR plates vs the field size acquired through the other modalities. The X-direction radiation field size was 0.5 mm smaller than the film and daily device and the Y-direction was 0.8 mm larger. The cause of this discrepancy was not determined, but one possibility is the nonlinear response of the CR plate to radiation. Both geometric penumbra from the source and secondary source scatter could have contributed to the larger Y-direction radiation field size as the Y-jaws are located above the X-jaws. However, this does not account for why the X-direction field size is smaller than the other modalities. As well, the light field width seemed to be consistently smaller than the detected radiation field width after accounting for the 2 cm nominal difference. Moving the jaws twice to acquire the image certainly adds to the overall uncertainty, but the shift is systematic. Possible reasons for this could be a nonlinear removal of the latent image in the penumbra region of the light field, although results are still within tolerance. The small differences between radiation and light field centers, 0.14 mm and 0.12 mm in the X- and Y-directions on average, show that even though the detected field widths have some differences, the centers are still very close to one another, which is reassuring when relying on the light field for a setup.

Comparing the methods of data acquisition, the effect of moving the jaws from a smaller or larger field size did not affect the results of the EDR2 film in any appreciable way, but did give differences in the CR radiation field size of up to 1.2 mm. In each method one of the CR radiation field sizes was close to the results of film and the daily device, but much

different in the other direction. Potential solutions to this problem are to irradiate two CR plates, one for each method, or to apply directional scaling factors to the algorithm once the true field size is known. Even so, without the corrections and by averaging the two methods, the results are within 1 mm of the film and daily device results and within 1.1 mm if not averaged.

Results from “eyeballing” film can give results only to within 1 mm at best and is not useful to identify trends.² Using 2D arrays as a surrogate for the light field assume a perfect calibration by the physicist when commissioned, but this suffers from the same problem: “The light is aligned with the 20 × 20 cm box on the DQA 3 when setting up”¹⁰ and “Analysis assumes the light field edges are aligned with one of the rectangular field marks on the Profiler 2’s surface.”¹¹ This does not discount the use of these devices, but calls into question their accuracy seeing that it depends on the physicist calibrating the device and their interpretation and desired accuracy of the light field edge.

Measurements using a jig and the EPID have been a common digital approach to light-radiation field congruence. Yet, again due to setup and interpretation differences, one study had interuser variability of 0.75 mm⁶ while another got differences of up to 2.5 mm between EPID measurements and nominal values,⁴ while yet another saw a maximum difference of 0.86 mm.⁵ Our results are not considerably better or worse than previous work, falling within these previously found ranges of values. One difference is that our method used the automatic control of jaw motion instead of relying on user adjustment of the field size; this is both a strength and drawback as the uncertainty is a limit of the linac system, but more accurately reflects what happens day-to-day in the clinic.

The reproducibility of the algorithm using two different CR plates was demonstrated, and the range of results in our study was well below what is required by QA guidelines. Additionally, the small effect of varying the MU value and light exposure time makes the method robust to machine output variations and bright and dim field lights. Performing all steps of the test including analysis takes approximately 10 min, the same amount of time as marking, irradiating, and processing a film, but has more precise results. Also, the lack of any custom-built jigs makes our test more easily implemented at any clinic that cannot afford to buy or build a jig. Assuming it gets verified with another tool already in use, this test could be used monthly to replace the current light-radiation field QA method or annually and after any machine repair and then coupled to the already established light-radiation field coincidence tool in place.

Additionally, our method can be extended to have more uses. MLC-light field coincidence, asymmetric jaw measurements, and crosshair walkout could all be measured using the same general procedure. If the crosshair can be determined to be truly accurate, individual jaw measurements relative to the crosshair could be done to identify individual offset jaws with accurate, quantifiable results. Other field sizes can be used with this method, but the difference of field sizes must be large enough that the maximum value of the radiation strip is not compromised by encroaching penumbra; we

suggest using a strip of at least 1 cm, i.e., $20 \times 20 \text{ cm}^2$ to $18 \times 18 \text{ cm}^2$, $15 \times 15 \text{ cm}^2$ to $13 \times 13 \text{ cm}^2$, etc. if using symmetric field sizes.

Knowing the point of reference chosen and its limitations is important. Using the crosshair is good since it is what most people use for alignment and has no intrasession variability. However, the walkout value of the crosshair should be determined first before it is relied upon. Additionally, while perhaps unlikely, the crosshair position can still potentially drift, which is why it is still checked on a monthly basis. Using the radiation field as a reference point is advantageous since it is what the patient or test actually experiences, and thus everything should be aligned to it; however, the jaw motion variability from one field size movement to the next can cause difference in results, as this study showed.

Other limitations of this approach include the need for an existing CR system and a relatively clean mylar window. Accumulated water spots could compromise the accuracy of the algorithm, although it would be possible to add more error-checking to the algorithm to reduce this effect. Additionally, although our CR system did not saturate with the doses given, other systems may saturate and this should be examined before implementing such a technique.

5. CONCLUSION

In this study, we developed a procedure to quickly and accurately quantify light and radiation field coincidence using CR photo-stimulable phosphor plates without the need for a custom jig. In addition, this method allows users to accurately locate the crosshair. The centers of the light and radiation fields can be spatially related to one another, allowing clinical physicists to gather meaningful results when performing monthly QA. The procedure is easy to perform if CR equipment is already available and does not require specialty equip-

ment or the construction of in-house equipment, allowing implementation by clinics without specialty equipment.

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