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New Method of Quality Control Test for Light and Radiation Field Coincidence in Medical Linear Accelerators

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ABSTRACT

Introduction: The evaluation of X-ray and light field coincidence in linear accelerators as a quality control test is often performed subjectively, involving the manual marking of films and their visual inspection following the irradiation. Therefore, the present study aimed to develop an objective method for the performance of this test leading to the increased levels of accuracy, precision, and speed for the measurement of X-ray and light field coincidence.

Material and Methods: The new method involved a portable, lightweight, and inexpensive device containing optically-shielded and non-shielded photodiodes to detect the location and dimensions of the light and X-ray fields. The obtained results were analyzed using purpose-written user-friendly software.

Results: On the basis of the results, this system could be a reliable method to measure the coincidence of the two fields with the accuracy of 0.5 mm and average field size standard deviations of Elekta Presice and Siemens Primus are 22.47 mm^2 and 22.36 mm^2, respectively. The result was well within the tolerance recommended by the American Association of Physicists in Medicine task group report number 142.

Conclusion: The proposed method allows accurate and precise measurements through a largely automated process. Therefore, the measurement results benefit from the reduced level of subjectivity or human error, compared to the standard film-based technique.

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Introduction

Quality control (QC) tests for linear accelerators, usually recommended by international institutions (e.g., AAPM), are fundamental parts of the radiation oncology departments' program for quality assurance (QA) [1]. The light field produced by a medical linear accelerator is frequently used during patient setup to verify the correct direction of the treatment beam towards the patient's body. This process requires the coincidence of light field and X-ray treatment field. Therefore, the examination of light and radiation coincidence field is an important QA test.

One of the important QA tests is the light/radiation field coincidence, which has a direct impact on dosimetric accuracy. In case the difference between the radiation field and the light field is beyond the acceptable range defined by the American Association of Physicists in Medicine (AAPM) task group report number 40, it might result in inaccurate tumor radiation leading to serious damages to the healthy adjacent tissues. Consequently, it is essential to develop new methods to minimize the probability of errors by efficient QA, insuring high-level geometric accuracy of the treatment [2].

Regular tests and verifications should be carried out to enhance the geometric and mechanical accuracy of medical linear accelerators [3]. The previously used simple methods of QA tests can no longer be used due to their time and accuracy problems [4]. To this end, a new method has been developed in the current study to change the task from a subjective test into an objective one aiming to enhance the accuracy, precision, and speed of light/radiation field coincidence test (i.e., one of the important monthly QA tests).

The AAPM Task Group numbers 40 and 142 recommended the deviation of 2 mm or 1% between the radiation field and light field as acceptable [5, 6]. The conventional method includes using a film and making four thin metal obstructions at the corners. In the conventional method, light field borders are usually evaluated by visual observation [7].

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Currently, various methods are employed to verify the coincidence between light and radiation fields. Sheu et al. used a phosphor plate to examine the accuracy of computed radiography (CR) system for light/radiation field coincidence QC test and to examine if this technique can achieve the accuracy level required for a routine linear accelerator [8]. Njeh et al. developed a method for testing light/radiation field coincidence using electronic portal imaging device (EPID) and a special phantom [9].

The purpose of this study was to develop an accurate, cost-effective, and real-time method to verify the coincidence of light and radiation fields through turning the subjective task into an objective. In fact, this study was targeted toward the the elimination of the inevitable errors caused by human factors.

Materials and Methods

The QC test of the coincidence between X-ray and light fields was performed by means of low-cost photodiodes, two linear accelerators, a Siemens Primus (Siemens AG, Erlangen, Germany) in Reza radiation oncology center, and an Elekta Precise (Elekta, Stockholm, Sweden) in Imam Reza (AS) Hospital of Mashhad, Iran.

The QA procedure using this method consisted of four steps performed by the user, including setting up the QA tool on a couch, clicking the start key on the computer software, exposing the radiation, and clicking the stop key on the computer software after about 5 sec and before the termination of radiation. The rest of the procedure was performed automatically and the obtained results were displayed on the software screen.

The PIN photodiodes (photodiodes containing three layers of P, I, and N) connected to 32 analog-to-digital converter channels of 12-bit and 2 dsPIC microcontrollers (digital signal controllers of microchip company) were the main hardware elements of this method. Finally, the data was transferred from the master microcontroller to a USB port of a computer. Computer software was used to perform the final analysis and display the results and the graphical diagram. It should be noted that the room lights were turned off during the performance of the test.

Photodiodes

A sensitive high-speed silicon PIN photodiode was used to detect both X-ray and visible light. This employed photodiode was 5.4 x 4.3 x 3.2 mm (LxWxH) in size and had a sensitive area of 7.5 mm^2 and capacitance of 25-40 pF under reverse bias. The photodiodes were arranged on a board and on the sides of 4 squares around a 100 x 100 mm field. These PIN photodiodes were employed in reverse bias mode. Moreover, the high reverse voltage was selected to achieve high sensitivity. However, the increase of reverse voltage could elevate the probability of noise. Therefore, a photo-diode with 25-50pF capacitance was utilized to have a fair comparison between sensitivity and noise [10].

Since this photodiode was designed to detect the sensitivity of photons ranged 430-1100 nm, it was not a challenging issue to detect visible light within the range of 400-700 nm. However, the detection of X-ray would be problematic since X-ray has a wavelength of less than 10 nm, and the detector receives X-ray and visible light simultaneously. Accordingly, there would be no tangible X-ray stimulation. This problem was tackled using a thin layer of aluminum foil to shield the sensitive area of the photodiode from visible light. The aluminum cover would completely filter the visible light, and negligible attenuation was applied to X-ray photons. The implementation of an aluminum layer with a thickness of 0.09 mm, and attenuation of 6 MV X-ray photons were computed, as follows [11]:

$N = N\mathbf{0} .e^{-\mu x}$

$\mu x = 0.07 \times 0.009 = 63 \times 10^{-5}$: $N/N\mathbf{0} = e^{-0.00063} = 0.99937$

This indicated that 99.937% of photons would pass through the aluminum foil, and therefore X-ray attenuation could be ignored. The X-ray and light fields were supposed to be square-shaped; consequently, photodiodes were arranged in a way that they could cover 4 squares with size of 100 x 100 mm. Figure 1 shows the arrangement of the photodiodes on the board with the yellow color representing the X-ray detectors and the blue color showing visible light detectors.

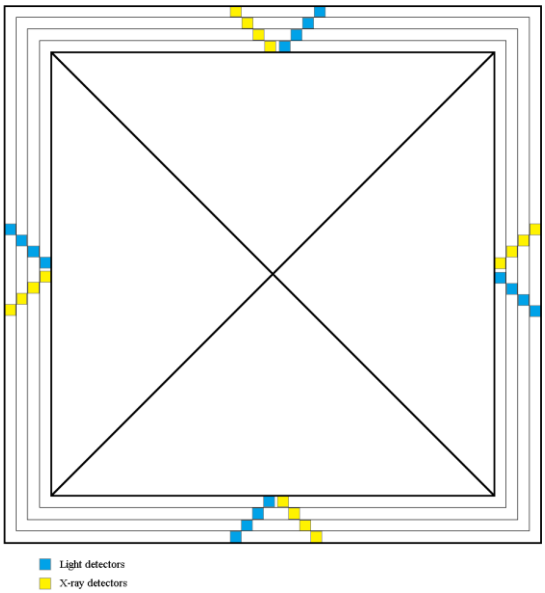

Figure 1. Location of the X-ray detector and light detector photodiodes (X-ray detector photodiodes and light detector photodiodes are specified with yellow and blue colors, respectively)

Processing

The output signals of the photodiodes were sent to 32 channels of 12-bit analog-to-digital converters (ADC) among which 16 channels were for visible light-sensitive photodiodes and the other 16 were for X-ray sensitive photodiodes. The 12-bit ADCs supported 500-kilo-samples-per-second (ksps), and included a sample-and-hold (S&H) circuit [12].

The digitized outputs of each ADC were processed in a dsPIC microcontroller. The X-ray photodiode signals were preprocessed in a slave microcontroller, and the obtained results were sent to a master microcontroller, which received and performed the preprocessing of the visible light photodiode signals at the same time. Master dsPIC transferred the output to a USB port. A schematic block diagram of the whole process is shown in Figure 3.

Computer Interface Software

As mentioned in the previous section, the output data was transferred from the master microcontroller to the computer interface software using the USB port. As demonstrated in Figure 3, the interface software was composed of three sections. The main tab section contained the graphical display and ADC values of each photodiode, the byte tab section involved the detailed received bytes, and the border setting tab was used for the calibration of the border detection algorithm.

The apparent configuration of the graphical diagram as well as separate threshold assignments for X-ray and visible light detection levels were the border setting facilities. In the text display, all the raw data received from the microcontroller were displayed in real time. In the graphical display, two squares were shown, each demonstrating the location and the size of the X-ray and the light fields. In the graphical display, the yellow color represented X-ray and the blue color showed light field. The calibration part in the computer software was designed to have fine adjustments in the thresholds of the steps.

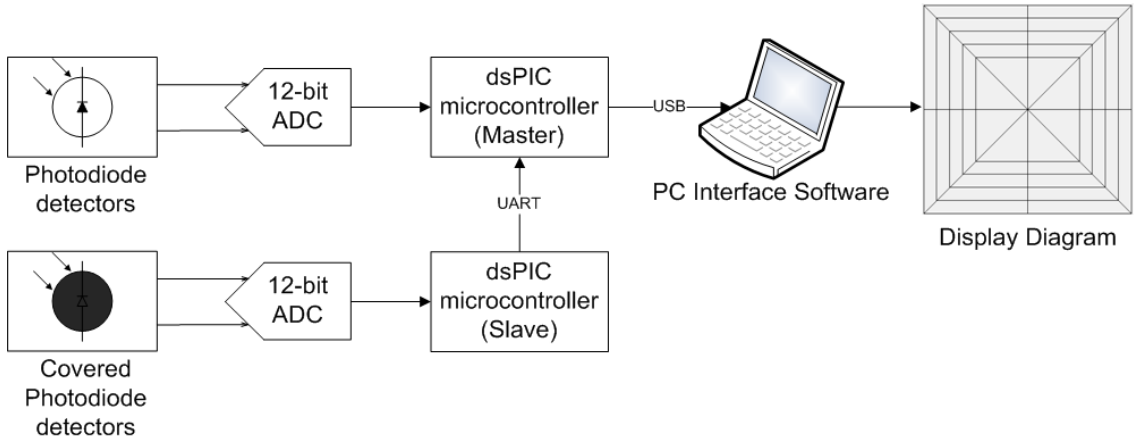

Figure 2. Block diagram of the proposed method for light/radiation field coincidence test

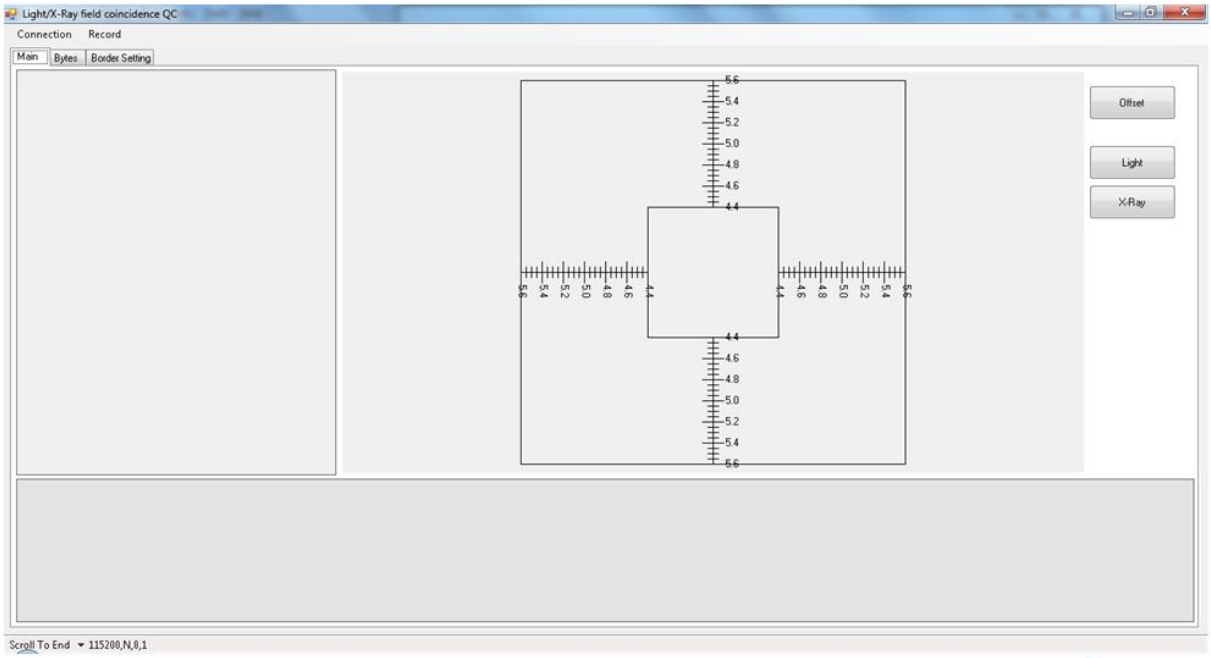

Figure 3. Software designed for using the light/radiation field coincidence as a quality control device

Results

The accuracy of the proposed method was 0.5 mm, which was higher than that of the previous methods. Furthermore, this newly designed method was compatible and its performance was far better than the requirement of the AAPM TG40 (2mm) for light/field coincidence QC test.

In square radiation and light field, each side had a continuous photodiode territory with the width of 12 mm, and the dimensions could be measured with a resolution of 0.5 mm on each side. In order to achieve this accuracy, the output was analyzed in an algorithm to specify the percentage of each photodiode underexposure.

In some linear accelerators, the light field was turned off automatically before the initiation of radiation exposure (e.g., Siemens Primus). However, the light field was on during the radiation (e.g., Elekta Precise) for other accelerators. This issue did not hinder the procedure since there was an option to choose each of the methods in the Option box. Accordingly, there was no need to accurately adjust the light field in a special position on the QA device.

The obtained results of the light/radiation field coincidence QA test using the proposed method for the two linear accelerators are presented in Table 1 (each has been repeated 5 times to enhance precision). Table 2 presents the results for the light/radiation field coincidence QA test using the traditional film method. For higher precision, each test was replicated 5 times. To evaluate the system, the tests for each method were carried out 5 times during a month with an average frequency of 6 days with no changes in the jaw calibration and light field. P-values for paired tests are presented in Table 3.

Table 1. Light/radiation field coincidence quality assurance test using the proposed method (The number of repetitions = 5)

Linac	Energy (MV)	SSD (cm)	Average Field Size (mm^2)		Standard Deviation (mm^2)	
			Xray	Light	Xray	Light
Elekta Presice	6	100	10050.00	10039.95	0	22.47
Siemens Primus	6	100	10000.00	10010.00	0	22.36

Table 2. Light/radiation field coincidence quality assurance test using a film method (The number of repetitions = 5)

Linac	Energy (MV)	SSD (cm)	Average Field Size (mm^2)		Standard Deviation (mm^2)	
			Xray	Light	Xray	Light
Elekta Presice	6	100	10174.95	9970.00	101.73	130.38
Siemens Primus	6	100	10000.05	10000.00	79.14	117.26

Table 3. P-values of the paired tests of the proposed method and the traditional film method

Linac	Field	P-Values of the paired tests
Elekta Presice	X-ray	0.052
Siemens Primus	X-ray	0.999
Elekta Presice	Light	0.246
Siemens Primus	Light	0.871

Discussion

The present study aimed to evaluate the efficacy of the proposed method for light/radiation QC tests. Considering the values in table 1 and table 2 which makes a comparison between the proposed method and the conventional method, and also taking into account the calculated P-values (table 3),the simple QA method has high accuracy and precision. Moreover, it is a cost-effect, light-weight, and portable device compatible with all kinds of linear accelerators. The QA tool consists of a portable device transferring data to a computer. Currently, radiation oncology centers ignore the light/radiation field coincidence QC test and use subjective methods as they consider this QC test time-consuming and expensive. It should be noted that this test is carried out in a subjective and conventional manner through which accuracy and precision cannot be measured precisely [1].

The phosphor plate approach introduced by Sheu et al. was performed with 6MV and an SSD of 100 cm for all the measurements. During the tests, the lights were turned off to control the light affecting the phosphor plate. The accuracy of this method was reported as less than 1 mm [8]. Njeh et al. used the Electronic Portal Imaging Device (EPID) to image the special phantom, and estimated the accuracy of light/radiation field coincidence test as 1 mm [9].

The proposed method in the current study was a simple approach to be substituted for the subjective traditional methods for light/radiation field coincidence test. The introduced method had higher accuracy and lower cost, compared to those suggested by Sheu et al. [8] and Njeh et al. [9]. Since traditional tests were time-consuming, some radiation oncology centers used to be reluctant to comply with the complete QC tests. However, for the newly-designed test, it took only three clicks to obtain the expected results for each test. Therefore, the lack of time would not be a problem in these QC tests. It sould be noted that since film sensitivity decreased at high dose levels, using radiology films for this QC test affected the accuracy and precision of detecting the X-ray field borders [7].

Conclusion

For the light/radiation field coincidence QC test, the light and X-ray field borders could be detected with an accuracy of 0.5 mm and average field size standard deviations of Elekta Presice and Siemens Primus are 22.47 mm^2 and 22.36 mm^2, respectively. The obtained results were completely acceptable by the AAPM task group number 142 defining the tolerance level of 2 mm for this test [5].

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