The role of high-energy computed radiography (CR) in radiotherapy

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Abstract Computed radiography (CR) imaging has high irradiation tolerance and it is easy to archive CR images along with other image information by Digital Imaging and Communications in Medicine (DICOM) format, and to process them. CR can be used in radiation Quality Control (QC) task and verification of treatment setting-up. In this paper, the role of high-energy CR in radiation oncology is studied. The patients were imaged by CR system and EPID before radiotherapy. All verification images were acquired with 1–2 MU (Monitor Unit) using 6 MV X-rays. QC for a linac was done with film and high-energy CR to collect the data on daily, weekly and monthly basis. The QC included Multileaf Collimators (MLC) calibration and mechanical iso-centre check. CR was also adapted to verify patient position, the film was used to compare with digitally reconstructed radiographs (DRR) and portal image from EPID. Treatment setting-up was verified based on the result of comparison. High quality verification images could be acquired by the CR system. Comparing to EPID, the results showed that the system was suitable for practical use to acquire daily verification images, and it was useful to fulfill part of quality assurance (QA) in radiation oncology. The quality of image acquired by the high-energy CR system is comparable or even better than DRRs and portal images. The final treatment set-up for the patients could be verified more accurately with the CR system.

Key words Computed radiography, Verification images, Quality control, Radiotherapy

1 Introduction

Accurate radiotherapy could determine therapeutic effect, and high accuracy is an obligation for precise dose prescribing. Quality assurance (QA) and quality control (QC) is a prerequisite for real-time treatment setting and a major task of medical physicists. Generally, part of the QA task is done with films and position verification is done with an electronic portal imaging device (EPID). Computed radiography (CR) has emerged recently as a useful and cost-effective method for portal imaging of radiography[1,2], as the CR images can be conveniently displayed, enhanced, and stored for clinical evaluation of patient positioning.

Primarily, CR was used for diagnostic imaging in departments of radiation oncology. The treatment portal fields were imaged with a silver-halide film sandwiched in a cassette between lead and/or copper screens[3]. But the tissue contrast of the images is low due to high energy photons used for the treatment. Therefore, the traditional method of portal imaging using films is gradually replaced with electronic imaging based on video, scanning liquid ion chamber (SLIC), and amorphous silicon (a-Si) EPID[4]. CR systems provide two-dimensional data of high resolution, and require virtually no time for setting-up or post-processing to obtain useful data. Digital processing can be used to further enhance the image contrast. Thus, routine QA tests can be performed periodically, including verification of the consistency of portal imager operation, and ensuring the compliance with performance specification limits established during acceptance tests.

In this paper, digital portal images acquired by CR system are compared with conventional film method, in terms of image quality and efficiency of digital data processing, and the role of high-energy CR system in QA and QC of radiotherapy is discussed.

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2 Materials and methods

2.1 Materials

AGFA CR 25.0 scanner, AGFA CR QS 3.0 workstation and CR QS radiotherapy software, and AGFA MV high-energy imaging plate (CR RT 1.0 Low Dose: 0–0.1 Gy; CR RT 1.5 High Dose: 0.1–4.0 Gy) were from AGFA, Germany. LANTIS network and Siemens ONCOR LINAC (with 29 pairs of leaves) were from Siemens, Germany. CMS XIO TPS software (XIO 4.33.02) was provided by Computer Medical System Inc. USA. Comparison of the two data groups acquired from CR and EPID was performed with T test of the paired samples.

2.2 CR system

This system acquires portal images up to 35×43 cm^2. It has a very wide dynamic range. Two hours after exposure, 70% of the absorbed energy is kept, without visible loss of information upon readout. Image retention exceeds 45% after 24 h.

2.3 Leaf calibration

Bar strip and special multileaf collimator (MLC) series were used to study the leaf positioning accuracy. They were designed by CMS TPS and were transferred from LANTIS server to radiotherapist workstation. Data were gathered from a high dose imaging plate (IP) template after irradiation, and were analyzed with CR QS radiotherapy software.

The couch height was adjusted to the distance from the source to the IP (SID) of 100 cm. The gantry angle was adapted to 0°. All measurements were performed using 6 MV X-rays. In order to verify its reproducibility, both the short- and long-term reproducibility of the leaf gap widths were investigated[5].

2.4 Mechanical iso-center

The radiation iso-center position and optical indication of the iso-center and their relative alignment is a complex procedure with many aspects being inter-related. A narrow slit of 0.5cm×20cm and 2 MU segments was used to study the mechanical iso-center.

For the rotation axis of the collimator, an IP template was put on the treatment table, with the gantry and table angles set to zero, and the SID to 100 cm. The crosshair position should be marked when the collimator was rotated to 0°, 45°, 90° and 135° as illustrated in Fig.1. The iso-centers of treatment table and gantry were similar to the collimator.

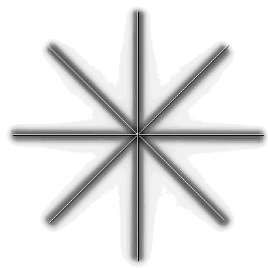

Fig.1 Iso-center of the collimator. All points were centered within a *Φ*2 mm circle.

2.5 Light and radiation coincidence

An IP was placed perpendicular to the beam central axis at the iso-center. The edges of the light and the crosshair were marked before the CR was exposed. The difference between the edges of the light and radiation fields was checked on the CR, for example, using a densitometer to establish the radiation filed edge. The size of the radiation field was compared to the light field size, and the radiation field centre was compared to the crosshair position.

2.6 Portal verification

Portal imaging is a critical component in radiation therapy for radiation field setting-up and verification[6,7]. CR imaging has the high irradiation tolerance, and one hardly needs image-renewing because of unsuitable imaging parameters. The digital portal images can be processed to enhance the display contrast of anatomical structures. In addition, software is available to register the digital portal and simulation images to evaluate treatment setting-up accuracy. A segment of 2 MU was given before treatment to acquire the portal image being viewed on the monitor of the CR system. Twenty patients were imaged by the CR and EPID systems before radiotherapy, respectively. A transparent plate with a cross length marker was inserted into the collimator before the exposure, used as a reference to determine deviations of the iso-center. In order to decrease artificial errors, two doctors were assigned to do the image comparison, independently, acquired by the CR and EPID to the digitally reconstructed radiographs (DRR). The portal images included images of head and neck (6 patients), thoraces (6 patients), and pelvis (8 patients). The difference determination was done by naked eyes, as the software for comparing the CR images was not available yet. Two groups of data were compared to exclude the statistic difference, and the result is negative (the p value is > 0.05 in X, Y and Z axis). The results are shown in Table 1.

Table 1 Position errors (in mm) in the X, Y and Z axis*

Detectors and methods			Patient No.																				p value
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	10	
X	Doctor 1	EPID	3	3	4	3	4	3	2	6	2	3	4	5	4	4	3	3	4	3	3	3	0.67
		CR	3	3	4	4	4	3	3	5	2	3	3	5	4	4	3	3	3	3	3	3	
	Doctor 2	EPID	3	3	3	3	4	3	2	5	2	3	5	4	4	3	3	4	4	3	3	2	0.72
		CR	2	4	3	3	4	3	3	5	2	3	5	5	3	3	3	3	4	2	3	2	
Y	Doctor 1	EPID	2	3	3	3	4	3	3	4	3	3	3	4	3	5	3	3	3	7	4	3	0.58
		CR	2	3	3	4	4	3	3	4	2	3	3	4	3	5	3	3	3	7	3	3	
	Doctor 2	EPID	3	4	3	3	5	3	3	4	3	3	4	3	3	4	3	4	4	6	3	3	0.67
		CR	3	3	3	3	5	4	3	3	3	3	5	3	3	4	3	3	4	6	3	3	
Z	Doctor 1	EPID	3	1	4	3	3	4	3	3	3	3	4	3	3	3	3	4	5	3	3	2	0.33
		CR	3	0	4	3	3	4	4	3	3	3	4	3	3	3	2	3	5	3	3	2	
	Doctor 2	EPID	3	0	4	3	4	3	3	4	3	2	2	4	3	3	3	2	6	4	3	2	0.43
		CR	3	0	3	3	4	3	3	3	3	2	3	4	2	3	3	2	5	4	3	3	

*X: the left to right, Y: the superior to inferior, Z: the anterior to posterior

3 Results

The CR images have high spatial resolution, but they are not consistent with the required precision by naked eyes for quality assurance. Although this is similar to the film[8,9], the CR images can be analyzed with software, making it more convenient to improve the calibration accuracy of CR in QA. The image gray in the edge of irradiation field is obviously different and the boundary can be detected with image analysis software. A frequently used method is edge-detection algorithm. In portal verification, CR images can offer sufficient clear images, which satisfy clinical requirement.

3.1 MLC calibration

The positional error of the MLC was validated using bar strip of uniform intensity. If the intensity bar strips did not have a straight edge, the leaf positions had to be recalibrated. The segment series and their connectivity were used to evaluate the dose distribution of every field[10]. So the MLC leaf global hyper-block or hypo-block could be checked. For static beam treatments, a leaf positioning accuracy with 1–2 mm standard deviation is generally accepted in the clinic[11], though Siemens guarantees an accuracy of leaf positioning within ±1 mm. The result has been discussed in another paper[2].

3.2 Linac QA

For mechanical iso-center check, all points should be located within a Φ2 mm circle around the iso-center. The result of collimator iso-center verification was shown in Fig.1. The iso-center of treatment table and gantry are similar to the collimator. For light and radiation coincidence, a 2-mm toleration of was used for field sizes <20cm×20cm, and 1% for field sizes >20cm×20 cm.

3.3 Portal verification

The CR system is able to obtain high-quality portal images at low doses as shown in Fig.2a. CR plates are used in radiation therapy clinics to acquire digital radiographic images for the purpose of verifying the treatment field size, shape, and location. In our department, we obtained hundreds of portal images of patients in the past two years. It was found that most of the CR images were clear enough to distinguish anatomy structures (e.g. bone, trachea). The digital portal images could be compared to DRRs, simulation images and EPIDs, facilitating verification of treatment setting-up. The CR system has been used to obtain digital portal images, without statistics difference (p>0.05) between the images by CR and EPID (Table 1). The portal image by EPID is from the same patient as shown in Fig.2b.

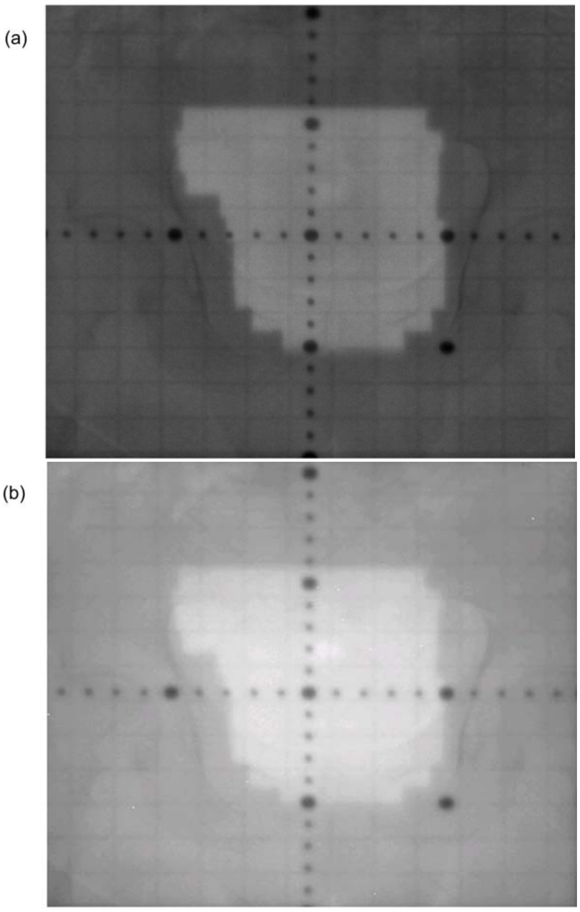

Fig.2 Compared with EPID, the CR images can get similar error, CR image (a) and EPID image (b) are referred to the same patient and and . It shows that the CR system is suitable for practical use to acquire daily verification images.

4 Discussion

In radiation therapy, it is important to periodically evaluate the treatment field position for clinical QA[12]. Being capable of providing two-dimensional data of high resolution, which can be post-processed to obtain useful data, a CR system offers higher contrast images. It is also a cost-efficient choice, without the needs of films, chemicals, dark room facilities and storage. CR images are stored in DICOM format (Digital Imaging and Communications in Medicine), and can be easily fitted into picture archival communication system (PACS) along with simulated image information.

4.1 MLC calibration

The positioning accuracy verification of MLC is an important part of the routine quality assurance package for IMRT treatments. CR image has high spatial resolution, but it is not consistent with the required precision by naked eyes. However, software can be applied to analyze the digital CR images and improve the calibration accuracy. The image grade at the edge of irradiation field is different from the other areas and the boundary of MLC leaves can be detected with image analysis software, in comparison with the planned radiation field boundary, and the MLC leaf location can be checked. Edge-detection algorithm is used frequently in this regard.

4.2 LINAC QA

Quality assurance in radiation therapy includes those procedures that ensure a consistent and safe fulfillment of the dose prescription to the target volume, with minimal dose to norma1 tissues and minimal exposure to personnel. Positioning and mechanical errors result in both underdosage of the target volume and unnecessary irradiation of normal tissues, leading to decreased local tumor control probability and an increase in side effects. For LINAC daily, monthly, yearly QA, radiation field/light field congruence and mechanical iso-center checks (collimator, gantry, and couch) can be done with CR system. In our institute, we will try to study the flatness and symmetry of X-ray and electron beam.

4.3 Portal verification

Uncertainties and errors in treatment planning systems may arise from any of the many steps involved in the treatment planning process. Expected and acceptable errors may be expressed either as a percentage error in high dose regions of the dose distribution such as the irradiated volume, or as distance in high dose gradient regions such as the build-up or penumbra regions of the distribution. Accuracy in patient positioning is a prerequisite to ensure precise coverage of the target volume. The routine way of checking the iso-center position is by analyzing two perpendicular irradiation portals (anterior and lateral fields) or EPID for most of the cases. In our study, we checked the positioning for the patients with head & neck, thoracic and pelvic cancers and compared the results of CR and EPID methods side by side, although there was no significant difference between CR system and EPID in terms of positioning error.

For patient portal verification, there is no economic software to realize automatic image registration. We must compare the images by manual registration or naked eyes, the errors evaluation contain some subjective factors. Different physician or physicist can declare different errors. In order to reduce subjective errors, senior or experiential professors or at least two doctors are necessary.

The CR screen has the same advantage as the film in that it is independent of the linac gantry. The high-energy CR response is similar to a film but the CR setting-up is easier. All the data can be acquired in a few minutes. The real-time response and the fast data handling reduce greatly the measurement time in acceptance and quality control procedures. X-ray films are disadvantageous due to the lack of digital image format and dynamic range, and due to their unchangeable imaging phase with increased retake rate. The high-energy CR also has the advantage with no need for developing and fixing film in darkrooms, it can avoid renewing imaging due to the unsuitable imaging parameters of X-ray film in great degree[13,14]. The contrast-enhanced CR images allowed the observer to more readily identify anatomical structures in the image. Digital processing could be used to enhance the display contrast in the portal image. CR is extensively employed to acquire digital radiographic images that are archived in a PACS. In CR, the film is replaced with a photo-stimulating phosphor plate (PSP). Each CR plate may be used numerous times, and the use of these digital images allows for easy storage and retrieval of patient data.

Both CR and EPID can be good candidates to create filmless radiation oncology department[15,16]. However, EPID can only image the radiation field and only be used in one accelerator due to the small Field of View (FOV) and low resolution of the new equipped accelerator. The CR portal imaging has the advantage that it is not machine specific, however it cannot be used for on-line assessment of patient or on-line adjustment. There is also the possibility of passing CR images in digital format directly to a portal image assessment terminal, thus eliminating the need for hard copies and without the loss in quality which would be associated with the transfer of film images into the system using a digitizer. CR is the easiest digital imaging when the old machine can not equip the EPID or there are no enough funds to equip the EPID on the all machines. CR is also a convenient method to realize digitalization in radiation oncology department.

5 Conclusion

CR plays a role in radiation oncology departments. It can be used for treatment position verification with IMRT, for some QA tasks in terms of congruence of actual radiation field/compared with light field, the mechanical iso-center assurance and multileaf performance. The digital computed radiography portal images might also be a potential tool to provide dosimetry verification with proper calibration and post processing[17,18]. The conventional film/screen could be replaced for the verification of real-time treatment position with CR system in the future[19,20].

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