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Technical Notes

Mechanical quality assurance using light field for linear accelerators with camera calibration

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A B S T R A C T

Mechanical Quality Assurance (QA) is important to assure spatially precise delivery of external-beam radiation therapy. As an alternative to the conventional-film based method, we have developed a new tool for mechanical QA of LINACs which uses a light field rather than radiation. When light passes through the collimator, a shadow is projected onto a piece of translucent paper and the resulting image is captured by a digital camera via a mirror. With this method, we evaluated the position of the LINAC isocenter and the accuracy of the gantry, collimator, and couch rotation. We also evaluated the accuracy of the digital readouts of the gantry, collimator, and couch rotation. In addition, the treatment couch position indicator was tested. We performed camera calibration as an essential pre-requisite for quantitative measurements of the position of isocenter, the linear motion of the couch, and the rotation angles of the gantry and collimator. Camera calibration reduced the measurement error to submillimeter based on uncertainty in pixel size of the image, while, without calibration, the measurement error of up to 2 mm could occur for an object with a length of 5 cm.

Introduction

In modern radiation therapy, intricate treatment planning and dose delivery are critical to applications such as intensity modulated radiation therapy (IMRT), stereotactic radiosurgery (SRS) and stereotactic body radiotherapy (SBRT), in which the positioning accuracy of the treatment system including the gantry, collimator, and couch is of the greatest importance. Positioning uncertainty in treatment could lead to poor target coverage, thereby risking the delivery of excessive and unnecessary radiation dose to nearby healthy organs at risk. This risk would be maximized for SRS and SBRT, which require narrower margins and deliver higher target doses [1–4]. Therefore, comprehensive quality assurance (QA), particularly concerning the mechanical accuracy of the linear accelerator (LINAC), is essential for spatially precise dose delivery. General QA tests for medical LINACs are recommended in the American Association of Physicists in Medicine (AAPM) Task Group (TG) 142 report [5], which is an update of the previous TG-40 report [6], which recommended annual testing of the isocenters of collimator, gantry, and couch rotation.

Traditionally, the mechanical isocenter is determined by irradiation of film at several different angles, yielding a so-called 'star-shot' image. Another useful method is the Winston Lutz's test, which uses a ball-bearing and film [7]. Recently, the method using an electronic portal imaging device (EPID) has advanced and is now even applicable to arc therapy [4]. Application of EPIDs has been widely adapted due to the ease of setup and its ability to provide real-time data [8,9]. The methods to measure the radiation isocenter have a sub-pixel accuracy that is based on image analysis, while for the mechanical isocenter, measurements depend on using somewhat dated techniques which rely, for example, on some type of pointer or ruler.

We designed a new method to obtain the mechanical isocenter without the use of irradiation. A method using non-radiation fields already exists, wherein an inclinometer or equivalent devices are used [10]. However, the use of the inclinometer is limited by the motion of the gantry, and the device cannot be applied to the rotation of the couch.

Provided that coincidence of radiation and light fields is assured, the method using the light field can provide an easy and time-saving procedure without loss of precision and with the saving of beam-on time. With a translucent imaging screen and a digital camera, we can perform a mechanical QA test conveniently. As recommended in TG-142, we can determine and test the accuracies of the isocenter of the gantry, collimator, and couch for annual QA. In addition, we can assess the gantry/collimator angle indicators, and the treatment couch position indicator for monthly QA. Furthermore, in order to maintain the accuracy of measurement with the method using the light field, we calibrated our digital camera, which is not ordinarily done.

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Method and materials

The isocenter of the LINAC is defined as the point at which the rotational axis of the collimator intersects the rotational axis of the gantry. In general, the isocenter can be defined as a small sphere in which the rotational axes of the gantry, collimator, and couch intersect [11]. The conventional approach to determine the isocenter is based on analysis of a radiation image acquired with either film or an EPID and exploits the differential x-ray attenuation among the materials comprising the object imaged. Our mechanical QA tool uses a light field rather than a radiation image. When light passes through the collimator, the collimator shadow is projected onto a translucent screen and the resulting transmitted image directed (via a mirror) to a digital camera and captured to produce a digital image.

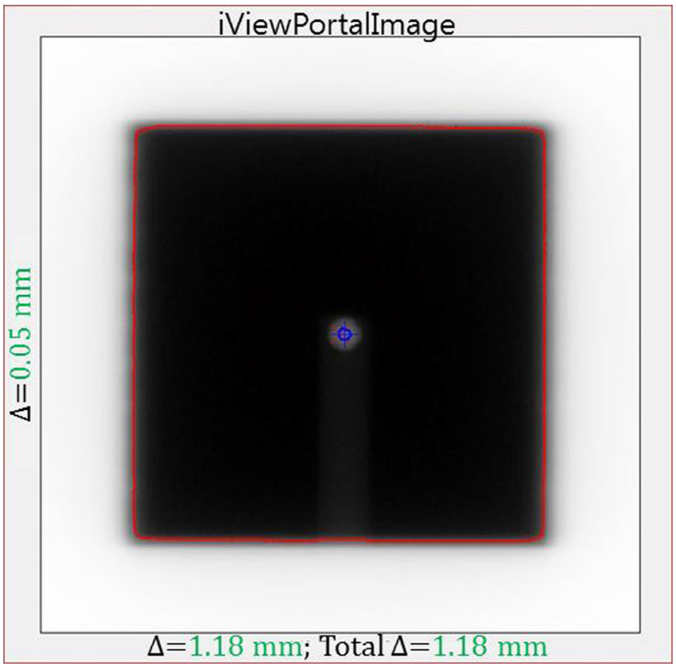

Figure 1. Results of the Winston Lutz's test to verify the coincidence of radiation and light fields. We measured the distance between the radiation center and the center of the collimator cross-hair, which yielded a value of 1.18 mm.

Prior to performing the light field-based QA, it is important to ensure the coincidence of the radiation and light fields. The Winston-Lutz test provides the offset between radiation center and the cross-hair at the center of the light field. The measured difference was 1.18 mm (Fig. 1). We can thus verify the coincidence of radiation and mechanical isocenters, with the latter identified using the light field.

In Fig. 2, we schematically illustrate the design of the device, wherein two different imaging screens are shown. A horizontal screen (screen (a) in Fig. 2) made of translucent paper was used for determining the rotational accuracy of the collimator and couch, while a vertical screen (screen (b) in Fig. 2) was for determining the gantry rotational accuracy. The vertical screen consisted of six inclined trapezoid-shaped plates to acquire the image of the light source positioned in the gantry and a central reference plate, which was parallel to the rotational plane of the gantry and aligned such that the lasers beams were centered on the plate. Grids were engraved on each section of the smaller inclined screens for camera calibration. Each of the trapezoidal screens is inclined by 3° with respect to the central plate because, otherwise, incident light parallel to the image screen cannot be imaged at all. Moreover, we accounted for this 3°-inclination when we performed the camera calibration for each group of image acquisitions. As explained in the next section, the camera calibration process included a projection process to compensate for this 3°-inclination. Since the isocenter is by definition the intersection of the three rotational axes, it is preferable that measurements concerning the gantry, collimator, and couch be incorporated in a single system.

Camera calibration

The accurate camera calibration is essential for any application involving quantitative measurements [12]. There are several

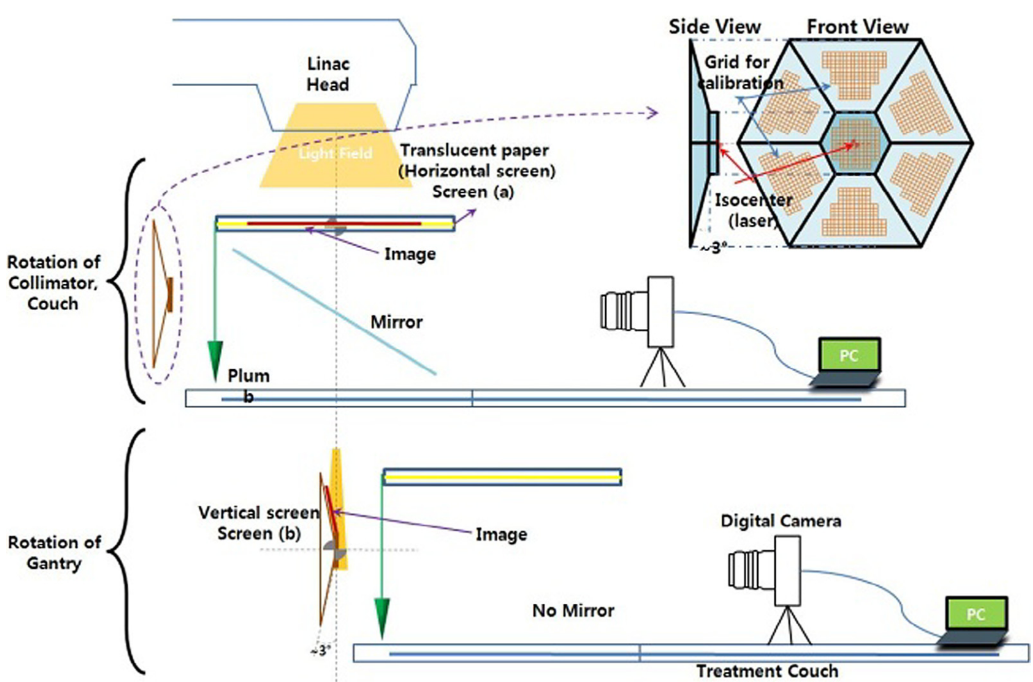

Figure 2. Schematic of proposed mechanical QA device: The horizontal screen was used for the QA of the rotation of the collimator and couch, while the vertical screen was used for the gantry rotation QA. The vertical screen consists of six inclined trapezoidal screens and a central plate comprising engraved grids that are used for the camera calibration.

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