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Short communications and technical notes

A photographic technique for quick assessment of mechanical isocenter of a linear accelerator

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ABSTRACT

Demands for mechanical accuracy of medical linear accelerators are increased due to the stereotactic and modulated rotational treatments. Mechanical inaccuracies affect the size and shape of the mechanical and radiation isocenters. In practice, the mechanical isocenter is defined by the intersection of rotational axes. However, there are no simple tools to check the properties of the mechanical isocenter in 3D. We introduce a new photography-based method for quick and sub-millimeter accurate determination of the mechanical isocenter. The method is based on image-processing algorithm and modified front pointer. The results demonstrate the quick measurement and visualization of the mechanical isocenter.

Introduction

Medical linear accelerators with a rotating gantry are based on an assumption that the rotational axes of the gantry, collimator, and treatment couch intersect in a single point, an isocenter [1]. Therefore, the definition of the isocenter is based on a surface that covers the cluster of isocenter points determined by rotational axes of the linear accelerator. Because of mechanical inaccuracies of the axes rotations it is better to speak about isocenter volume than isocenter point.

According to the AAPM quality assurance (QA) protocol for medical accelerators [1], mechanical and radiation isocenters are recommended to be verified regularly. However, feasible and accurate techniques or tools for QA of the mechanical isocenter in 3D are not available. At present, the mechanical isocenter is usually assessed by two pointers, a front pointer moving with a gantry, collimator or couch rotations and a fixed pointer independent on rotations whose distances should be measured [2]. The distances can also be measured using photo-detector plate if the front pointer is replaced by a laser [3]. Due to the lack of easy and accurate systems to register these distances in 3D with all collimator and gantry angle combinations, these kind of tests does not necessarily reach sub-millimeter accuracy in 3D.

Many techniques have been introduced and published for the determination and QA of radiation isocenter [4–8]. These methods are often based on radiochromic film, electronic portal imaging devices (EPID) or phosphor panels. However, the radiation isocenter may deviate from the mechanical isocenter [9] justifying independent determination of mechanical isocenter because a small and accurate radiation isocenter can be achieved only if the mechanical isocenter is verified to be stable and precisely adjusted.

Verification of the accuracy of the mechanical isocenter requires an exact, repeatable, and automated method to track changes over time. In the present investigation we introduce a new photography-based method for the determination of mechanical isocenter. A modified front pointer, camera and an automatic image-processing algorithm were used to determine and visualize the size and shape of the mechanical isocenter in three dimensions. The method is based on automated analysis of the series of single images acquired during gantry and collimator rotations. The developed method for quick evaluation of mechanical isocenter with sub-millimeter accuracy produces also trend curves to detect slight temporal changes in size and shape of the mechanical isocenter.

Materials and methods

Technical solution

The introduced system consists of a standard digital single-lens reflex (DSLR) camera, remote trigger, flash module, modified front pointer, and image-processing software (MATLAB, The MathWorks Inc., Natick, MA). The standard front pointer (Varian Medical Systems Inc, Palo Alto, USA) was modified by fixing a high-contrast

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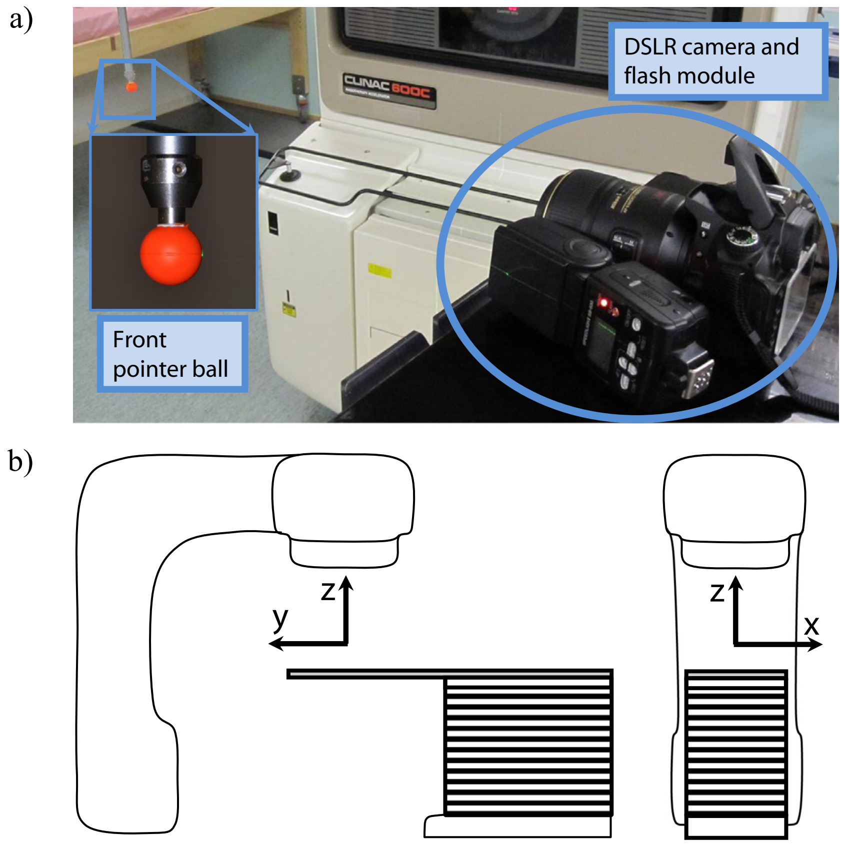

Fig. 1. (a) An example of the imaging setup with gantry angle 0° and couch rotation 90°. Modified front pointer is the imaging object. Tip of the front pointer is a plastic ball with a diameter of 12 mm. (b) Coordinate directions (*x*, *y*, and *z*) used in the image analysis and results.

ball with a radius of 12 mm to the tip of the front pointer (Fig. 1a). This ball is an imaging object and the center of the ball is automatically detected by the image-processing software from images captured at different collimator, gantry, and couch angles. The software also includes tools for image preparation, isocenter visualization and trend curve analysis.

Image capture

In the beginning of the isocenter test, the center of the ball was positioned at the assumed mechanical isocenter indicated by the patient positioning lasers. For data acquisition the camera was placed on the couch and the front pointer was fixed to the gantry (Fig. 1a). Images were captured by using a remote trigger to prevent camera movements during image acquisition. Imaging parameters (aperture, exposure time, ISO value, and focusing) were kept constant for all images. The depth of focus was adjusted to be short to blur the image background thus helping automated ball detection from the captured images.

The first image set with camera on the couch with couch angle 0° was acquired during rotation of the gantry and collimator angles from −180° to 180° and from −165° to 165°, respectively. In the second image set, the couch angle was 270° and the front pointer was imaged using same gantry and collimator angles, except the gantry angles between 180° and 315° to avoid collision of the gantry with the couch.

Data analysis

All the acquired images with corresponding gantry angle, collimator angle, and couch angle were loaded in image-processing software and the ball was recognized from each image. The recognition starts by thresholding the ball in hue-saturation-value color space. The edge of the ball is then determined using Sobel edge detection method [10] and center of the ball is determined using the circle Hough transform [11]. These circle center coordinates correspond now to location of the front pointer in pixel space. The pixels are converted to millimeters by using the diameter of the ball (12 mm) as a reference.

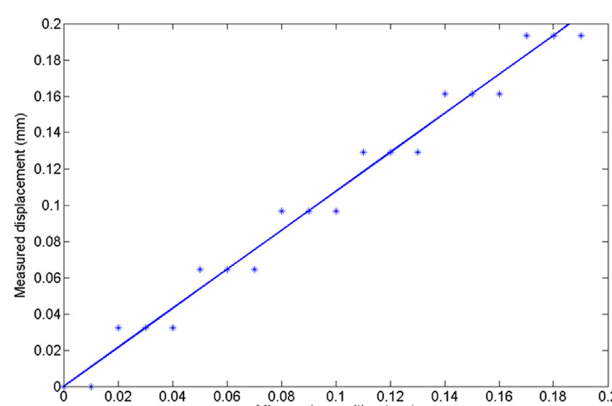

Fig. 2. Measured displacements as a function of micrometer position with the linear fit to the measurements. Displacements were analyzed in pixel space and converted to millimeters using the size of the ball as a reference (1 pixel = 0.032 mm).

Using the acquired images at different angles the centers of front pointer ball were determined in *x*, *y*, and *z*-directions (Fig. 1b). First, ball displacements due to gantry and collimator rotations were determined in the gantry rotation plane (*xz*-plane). Second, the