An isocenter detection and verification device for use in proton therapy

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We developed a new device for isocenter detection and verification for use in proton therapy. This device can be used to confirm the isocenters of a room laser, a digital radiography system, and a rotational gantry. Agreement between the isocenters of a room laser and a digital radiography system was examined visually. We used the star-shots method for detecting and verifying the rotational gantry isocenter. The gafchromic film could be irradiated with this method using a 2 mm slitted 200 MeV proton beam. The isocenters of a room laser and digital radiography system were in good agreement. The size distribution of the isocenter by the star-shots method was <2 mm, which is the value recommended by the American Association of Physicists in Medicine Task Group 142. This new device can be used to evaluate comprehensive isocenter detection and verification for related equipment. Subsequent checking using this new device will decrease the uncertainty in measuring an isocenter. When using this device, the working time was significantly reduced to about 30 min, including preparation. These measurements should be useful for high accuracy daily treatments. © 2012 American Institute of Physics. [<http://dx.doi.org/10.1063/1.4771576>]

I. INTRODUCTION

Quality assurance (QA) is an important part of all processes involved in photon and proton therapy. Recently, technical methods have been introduced in several protocols for the practices and recommendations for QA in external photon radiation therapy.^{1,2} In these papers, one quality index for the rotational gantry used in radiotherapy was the accuracy of the isocenter position. The isocenter of an installed rotational gantry is characterized as the locus of the perpendicular distances of beam center passing through a small collimator mounted on the gantry, in relation to the mechanical isocenter which is the mechanical center of rotation of the gantry.^{1,3} The isocenter of the machine tends to blur slightly during gantry rotation due to alignment errors and lack of mechanical stiffness of the gantry structure.

There is a need to evaluate the isocenter volume to achieve good accuracy with a beam delivery system. The swing during gantry rotation with a heavy gantry in a proton beam delivery system may increase the isocenter volume. Thus, the irradiation error may increase because of mechanical error when a small field and a spot scanning method are used.⁴

The proton therapy equipment used in our institution is mounted with digital radiography systems that cross vertically and horizontally. These systems that are used for positioning patients have another isocenter. Thus, there is a need for the isocenter of the rotational gantry to coincide with that of digital radiography systems.

Using the test of Winston and Lutz,⁵ we confirmed that the isocenter of the rotational gantry coincided with that of the digital radiography systems at 0° , 90° , $\pm 180^\circ$, and 270° using

an imaging plate (IP), gold sphere markers, and a 5×5 cm² patient collimator. However, this method could not evaluate the isocenters at multiple angles because it was necessary to change the IP at each angle.

Several methods have been introduced for optical isocenter, mechanical isocenter, and radiation isocenter determinations.^{6–11} In particular, the radiation isocenter is measured by the star-shot method, which is generally performed at multiple angles concurrently using one film or one IP.

In this study, we introduce a device that we developed for evaluating each isocenter of a room laser, digital radiography systems, and an irradiation proton beam. We also evaluated the performance of this device.

II. DESIGN SPECIFICATIONS

The isocenter detection and verification device we developed is shown in Fig. 1. Figure 2 shows a schematic diagram of the positional relationships of this device. Each of the dashed-line arrows in Fig. 2 indicate the proton slit beams used for the star-shots method. Figure 1(a) shows a support arm to fix the device on a treatment couch. Figures 1(b) and 3 show a 2 mm diameter steel ball in the center and a 6 mm diameter steel ring at the cardinal angles of 0° and 90° on the frame. Moreover, cross lines at the cardinal angles of 0° , 90° , and 270° are marked on the frame (Fig. 4). The frame was constructed with acrylic resin. Urethane foam was used inside the frame because a proton beam has the characteristic that the penumbra width increases in a high density material. Figures 1(c) and 5 are the same as the part in Fig. 1(b) that was used to affix the Gafchromic film (EBT2). The Gafchromic film was held in place between the parts shown in Figs. 1(b) and 1(c) using a neodymium magnet.

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FIG. 1. Three parts of the device. (a) Support arm to fix a device on the treatment couch. (b) This part is used to match the device to the center of the digital radiography system. (c) Instrument used to affix a film or IP.

III. SETTINGS AND IRRADIATION CONDITIONS

Prior to use, the device with the affixed film was attached to a treatment couch with a support arm. Then, the x-y-z values of the treatment couch were set as the reference position for daily QA. The center of the device was set at the nominal isocenter of the room laser by aligning the cross lines (Fig. 6). Moreover, the center steel ball of the device was positioned at the frontal and lateral centers of a digital radiography system. As a simple quality control for the room laser and digital radiography system, the distance moved was evaluated as the error in the two devices (Fig. 7). Subsequently, the device was irradiated with a proton slit beam at that position.

In this study, we selected 200 MeV protons generated by the synchrotron at the Proton Medical Research Center, University of Tsukuba (PMRC). The passive scattering nozzle included a beam profile monitor, a first scatterer, a second scatterer, a ridge filter unit, a range shifter unit, a flatness monitor, a multileaf collimator, a shield block, and two dose monitors (parallel plate ionization chambers). The ridge filter and the range shifter were not used for this study. A collimator with a 2 mm slit (Fig. 8) was installed in the nozzle. The slit was arranged parallel to the axis of gantry rotation. The irradiated gantry angle was set as shown in Fig. 9. The slit proton beam irradiated the device in the manner described above in either a clockwise (CW) or counter clockwise (CCW) manner. Finally, the irradiated film was marked with the pin mark at 0° , 90° , 180° and 270° .

FIG. 2. Schematic diagram of our new device. Dash line is crossed to multiple shows the slit proton beam. While (b) cannot essentially be divided apart, the figure shows to make it easy to see. Figure is not shown four pairs of magnet to attach the (b) and (c).

FIG. 3. Internal construction of Fig. 2(b). The position of the center steel ball is indicated by the black dashed arrow. The four magnets used for fixation are indicated by black arrows.

IV. ANALYSIS METHOD

The images from the digital radiography system were assessed by simple visual examination. This could intuitively confirm if the isocenter of the room laser coincided with that of the digital radiography system. By mismatching the steel ball and the center of the ring, we could also check the dis-

FIG. 4. Cross line of a cardinal angle is indicated by the black arrows.

FIG. 5. Internal construction of Fig. 1(c). The four magnets are indicated by black arrows.

placement due to the inclination of the digital radiography system.

The gafchromic film of a star-shots image was digitized with an ES-10000G flatbed scanner (Seiko EPSON Corp.) for DD-Analysis (R-TECH Inc.). The scan parameters were set at a resolution of 150 dots per inch (dpi), image type of 48 bit

FIG. 6. First set-up step is matching the room laser to the cross line on the frame. The device is view from lateral.

FIG. 7. Second set-up step is matching the steel ball to the image center of the digital radiography system.

FIG. 8. Patient collimator for producing a 2 mm slit proton beam.

FIG. 10. Analysis of the results for the star-shots method. Blue cross indicates the center of the rotational gantry. Red cross indicates the center of the digital radiography system defined by the pin mark in the second step described. Sky blue dashed lines indicate each beam axis.

full color, and red channel dynamic range. The number of scans was set at 5 times. Because of the possibility that the peak of each beam profile was displaced from the beam center, the center of the beam axis was determined as the center of 50% width of each beam. The center of the rotational gantry was defined as a virtual center where the perpendicular line of each beam was intersected with a minimum total distance. The center of digital radiography system was defined as the cross of the pin mark. Error was calculated as the distance between the virtual center of the rotational gantry and the center of the device.

FIG. 9. Two patterns of irradiation angles. We performed the star-shots method using these angles. (a) Conditions for CW angles. (b) Conditions for CCW angles.

TABLE I. Measurement results for the differences between the rotational gantry and the digital radiography system isocenters over five weeks.

Weeks	Difference between the center of rotational gantry and the center of digital radiography systems	
	Right-left direction (mm)	Up-down direction (mm)
1	0.47	0.78
2	0.30	0.84
3	0.35	0.62
4	0.22	0.79
5	0.48	0.63
Base line	0.26	0.65

V. RESULTS AND DISCUSSION

The verification and detection of the comprehensive isocenter showed that our device had good measurement precision and reproducibility. The isocenters of the room laser and digital radiography system are in good agreement within 2 pixels meaning within 0.6 mm. There were no contradictions for the assumed matches between the room laser and digital radiography system isocenters. The results of the star-shots method are shown in Fig. 10 for the errors between the isocenters of the digital radiography system and the rotational gantry. These results showed that the errors were <2 mm, which is a value recommended in the literature.¹ When the base line was defined as the initial measured value, the temporal change was up to 0.22 mm in the right-left direction and 0.20 mm in the up-down direction (Table I).

The star-shots method was used to measure the error on the gantry rotation plane. This method could not detect the error in the direction of the gantry rotation axis. However, this device could conveniently verify and detect the isocenters for related equipment. When we used this device, the working time was significantly reduced to about 30 min, including

preparation. The error in the direction of the axis of gantry rotation can be evaluated by the Winston and Lutz test.⁵

VI. CONCLUSIONS

Our device was confirmed to be able to determine the coincident isocenters of the rotational gantry, digital radiography system, and room laser used in proton therapy. This device has the benefit of directly measuring the isocenters of all the equipment, rather than relying on separate and independent checks. Separate and independent checks can increase the uncertainty of position reproducibility. These measurement methods should be useful for high precision daily treatments.

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