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ORIGINAL ARTICLE

A practical method to detect target failure of a helical tomotherapy unit

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Summary

Purpose: *Helical tomotherapy has been in clinical use for several years. One of the issues with a helical tomotherapy unit is the failure of detection of the x-ray target. In this study, we are proposing a method to detect potential failure of the x-ray target.*

Methods: *Currently, on-board detector data from a helical tomotherapy unit are collected and sent to TomoTherapy Inc. for comparison with the so-called gold standard for the unit. However, this is sometimes time-consuming. Furthermore, the clinical medical physicists have no access to this comparison procedure. In this study, we developed a practical method to detect target failure based on one of the monthly quality assurance (QA) procedures. The commissioning cross-plane profiles were used as the comparison baseline. Larger EDR2 film (35×43 cm) were set at source-axis distance (SAD) (85 cm) and shot with 1.5 cm solid water as build-up material and 10 cm solid water as backscattering material. Cross-plane profiles obtained from the EDR2 film were compared with the commissioning profiles.*

Results: *When the cross-plane profiles from monthly QA have 1° degree difference from the commissioning profiles, it is time that the target be changed.*

Conclusion: *This method enables the clinical medical physicists to easily evaluate the target status and to help improving the quality assurance of a helical tomotherapy unit.*

Key words: EDR2, helical tomotherapy, quality assurance, target

Introduction

Helical tomotherapy unit is a radiation therapy unit specially designed for intensity modulated radiotherapy (IMRT) and has been in clinical use for several years [1]. More than 100 units have been installed worldwide, according to the information on the website of TomoTherapy Inc (http://www.tomotherapy.com/centers/ctr_index.htm). The quality assurance of a helical tomotherapy unit has been investigated by several researchers[2-6]. However, one of the clinical QA issues for a helical tomotherapy unit, the detection of target failure, has not been addressed.

The x-ray target used in the TomoTherapy unit is unique in design. The rotationary target is hydraulically spun by water (directed to the target's saw tooth edge) from the high pressure cooling system. The cooling water also provides target cooling.

The reasons of the erosion of the target surface are unknown. We observed that the erosion area was like a circle slot and the width of the slot was much wider than the focal spot diameter. Therefore, the chemical reactions between the target alloy and the water in the region on either side of the beam track may be a possible reason.

Another reason is related to the target rotating bearing surfaces. The target surface may be deteriorated via two phenomena: the first is that the target rotating bearing surfaces provide the ground return path for the target current. There is a measurable increase in resistance with wear. With the wobble we observed on one target, it may have periodically lost the ground return path. The second is the forces induced by gyroscopic inertia caused by the target rotating in a plane 90° degrees perpendicular to the rotation plane of the gantry. One last observation was that the target assembly leaked water into the binary multileaf collimator (MLC) causing premature failure.

Until now, there is no publication discussing this issue in detail. A common method to detect the target failure is to collect the on-board detector data and send

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them to the TomoTherapy Inc. to compare with the commissioning data served as the so-called "golden standard". Clinical medical physicists have little access to this procedure. Thus, two common questions arise: how the target current status is and when it needs to be changed. Even though the comparison with the commissioning data can give some clues about how the target performs, it is time-consuming sometimes. Since the whole procedure for target replacement and calibration takes more than 10 hours, it will help solve some clinical issues (such as patient rescheduling) if we know when to replace the target in advance.

In this study, we proposed a practical method to detect a helical tomotherapy unit target failure based on one of the monthly QA procedures used in our center. The method is easy to perform for clinical medical physicists and it can detect target failure correctly based on our clinical experience.

Methods

EDR2 film

Larger EDR2 film (35×43 cm, Eastman Kodak Company, Rochester, NY, USA) was selected to perform one of the procedures for tomotherapy monthly QA check. The EDR2 film has a wide range of dose response (25-400 cGy), which is especially useful to collect dose information [7]. In the tomotherapy monthly QA an EDR2 film is set at a SAD of 85 cm and sandwiched between 10 cm solid water^{TM} (Radiation Measurements, Inc., Middleton, Wisconsin, USA) as backscattering material and 1.5 cm solid water as buildup material. The film was aligned with lasers (red and green lasers are overlapped in this procedure) and shot with open field (40 cm × each commissioned jaw setting; 5 cm, 2.5 cm, 1.0 cm, or 0.6 cm; 1.0 cm and 0.6 cm models may not be available depending on customer licenses. The beam-on time was 30 seconds. After the procedure was finished, the film was developed using a Kodak X-OMAT 5000 RA processor at a fixed temperature (38.3° C). The developed film was scanned using the VXR-16 plus Dosimetry Pro film digitizer by Vidar Company (Herndon, VA, USA). The scanning software was RIT (version 5.2) with settings of 178 µm spot size, 142.5 dots per inch (DPI), and 2.8 line pairs/millimeter. After scanning, a calibration curve was applied to convert optical density into dose. Depth (cross-plane) and cross (in-plane) profiles at the center of the film were analyzed and saved as text files for the later comparisons. Each jaw setting had two corresponding profiles (one in-plane profile and one cross-plane profile) and eight profiles were collected in total each month at our center.

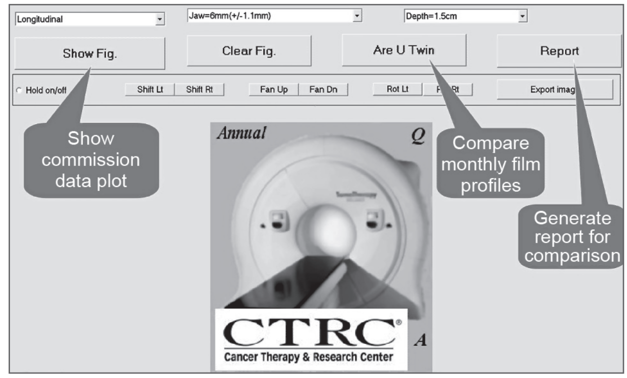


Figure 1. "Tomotherapy Annual Quality Assurance" software main interface.

"Tomotherapy Annual QA" Software development

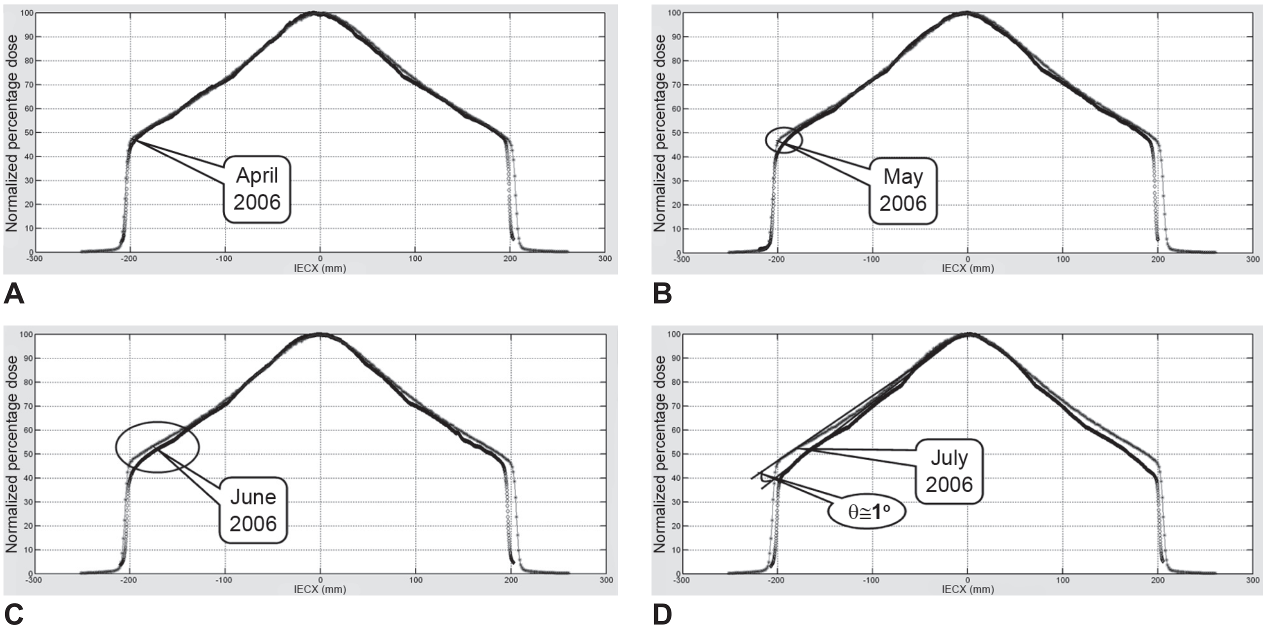
An in-house software called "Tomotherapy Annual QA" was developed to help the comparison process. The software was developed using Matlab 6.5 (The MathWorks Inc., Natick, MA, 01760, USA). The original goal of this software was to compare annual QA profiles with the commissioning data. The commissioning data were implemented into the software as the baselines. The exported cross-plane and in-plane profiles from RIT software can be read into the software and normalized for the comparisons. The software has several other functions such as profile shifting, profile fan rotating and report generating. The software can be used by other centers with a helical tomotherapy unit once their specific commissioning data are implemented, and the software is available on request. The main interface of the software is shown in Figure 1.

Among the functions, the fan rotating function enables the user to rotate the cross-plane profile along its central axis up or down. This function will help estimate the angle difference between the profile at the commissioning time and the monthly QA profile for a specific jaw setting and depth.

All the monthly QA profiles have been collected since the machine was commissioned and started in use in November 2005. In August 3 2006, the target was replaced and the total replacement time was about 20 hours including calibration of the unit after target replacement.

Results

Figure 2 illustrates the target failure process from April 2006 to August 2006, based on the methodology



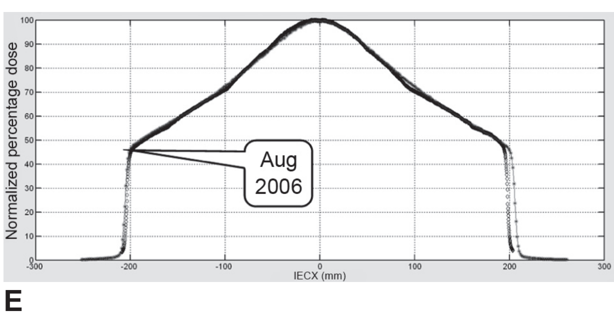


Figure 2. Comparisons between the commissioning profile and the monthly QA profile for each month from April 2006 to August 2006. The red lines represent the commissioning profile and the black lines represent the monthly QA profile. a-d: profiles collected for the previous target; e: profile collected after the target replacement.

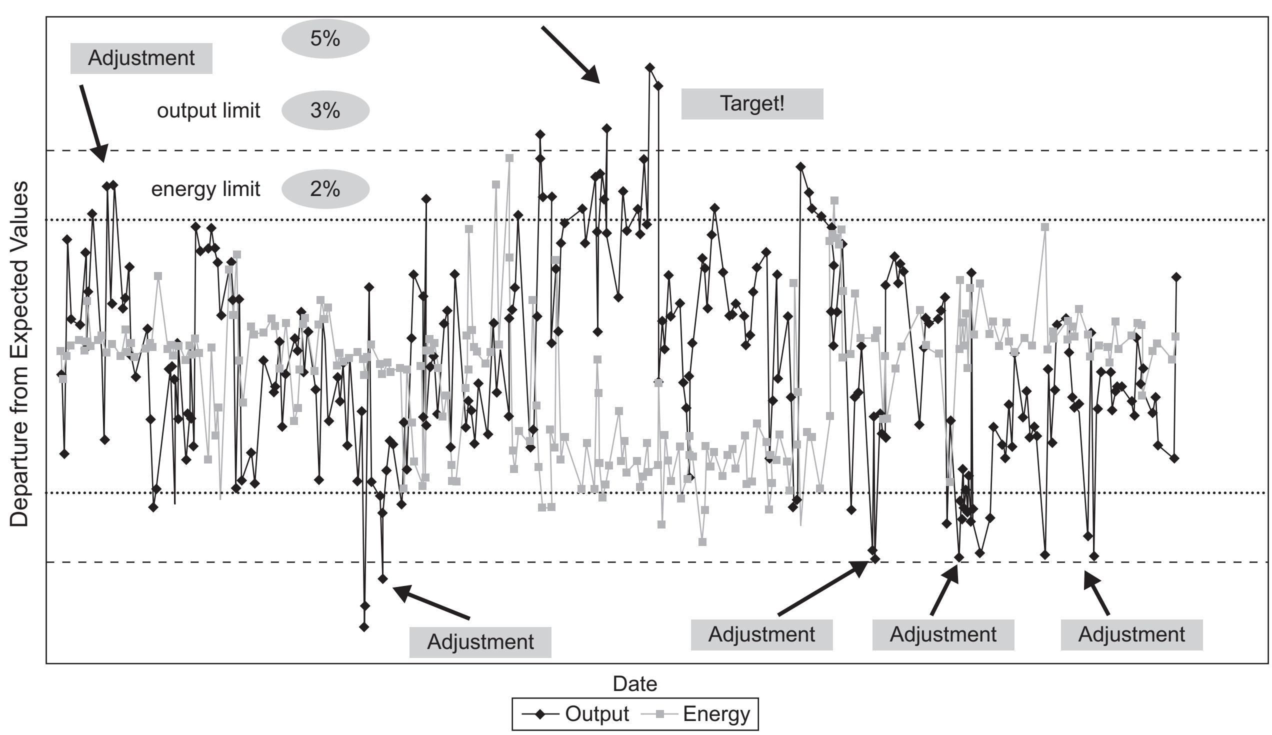


Figure 3. Relative daily output and energy plots for a year (November 2005 to November 2006). The outside boundary along y axis represents ±5%, the dashed lines represent ±3%, and the dotted lines represent ±2%.

mentioned above. Here we only present data for jaw setting 2.5 cm and cross-plane profile at a depth of 1.5 cm. The situations for other jaw settings (5.0 cm, 1.0 cm and 0.6 cm) are similar.

From Figure 2a to Figure 2e, the change of the cross-plane profile is clearly seen. The profiles split gradually from the edge to the center as the time goes on. When the splitting angle reaches about 1°, it is time to replace the target. The profile splitting may be because of the slot cut into the target by the electron beam. By adjusting pulse forming network (PFN) and injection current, the intensity at the beam center is set to be the same as the commissioning status; however, the lateral beam intensity gets less than normal. This beam profile causes the measured dose profiles to split from the commission profiles.

In order to double-check our finding, the daily QA trend for a whole year (November 2005 to November 2006) was plotted (Figure 3). Each time when the output or energy was over 3% off the baseline, we adjusted PFN and/or injection current to lower or increase the output or energy as explained by Balog et al.[2]. As the target was worn more, according to the daily QA trend the machine output and energy were adjusted more frequently. Both monthly profile comparison and daily QA trend can predict the target failure problem.

Discussion

This finding is helpful for a center to predict the target failure problem in advance. It is based on our clinical finding that we set the 1 degree difference between the monthly QA profile and the commissioning profile as criteria. The criteria may or may not apply to another center with a tomotherapy unit. However, if the profile splitting phenomena is observed and the splitting is much closer to the center of the profile, the target of the tomotherapy unit is recommended to be replaced. The future work for accurately figuring out the relationship between the splitting angle and target cut thickness can be done with the Monte Carlo simulations.

Conclusions

A practical method has been developed to predict target failure for a helical tomotherapy unit. The proposed method can be transferred to any center with a helical tomotherapy unit as long as the commissioning profiles are available. When the splitting angle is about 1° degree, it is the time to replace the target. On-site clinical medical physicists can easily use this method to predict target problem and it will help improving the QA of a helical tomotherapy unit.

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