Feasibility study of proton-based quality assurance of proton range compensator

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Abstract. All patient specific range compensators (RCs) are customized for achieving distal dose conformity of target volume in passively scattered proton therapy. Compensators are milled precisely using a computerized machine. In proton therapy, precision of the compensator is critical and quality assurance (QA) is required to protect normal tissues and organs from radiation damage. This study aims to evaluate the precision of proton-based quality assurance of range compensator. First, the geometry information of two compensators was extracted from the DICOM Radiotherapy (RT) plan. Next, RCs were irradiated on the EBT film individually by proton beam which is modulated to have a photon-like percent depth dose (PDD). Step phantoms were also irradiated on the EBT film to generate calibration curve which indicates relationship between optical density of irradiated film and perpendicular depth of compensator. Comparisons were made using the mean absolute difference (MAD) between coordinate information from DICOM RT and converted depth information from the EBT film. MAD over the whole region was 1.7, and 2.0 mm. However, MAD over the relatively flat regions on each compensator selected for comparison was within 1 mm. These results shows that proton-based quality assurance of range compensator is feasible and it is expected to achieve MAD over the whole region less than 1 mm with further correction about scattering effect of proton imaging.

1. Introduction
Proton therapy offers some distinct advantages compared to photon therapy. This is because the proton beam’s enhanced dose deposition region, known as the Bragg peak, may be exploited to irradiate tumor while the rapid fall-off in dose just beyond the Bragg peak may be exploited to increase sparing of normal tissue from damage (Smith 2006). As in conventional radiotherapy, treatment fields are shaped to a desired target profile using custom milled blocks generally made of brass. In addition to conventional blocks, a patient-specific device, known as a range compensator, is required in proton therapy to modify the beam range according to each patient’s anatomy and tumor shape. Compensators are field modifiers placed between the radiation source and the patient’s skin to modulate the beam range. Using a compensator, the distal end of a high-dose region in the dose distribution can be made to closely conform to the shape of the target. Therefore, it is critically important to ensure that compensators are manufactured correctly as planned. Recently, Li et al (2010) and Yoon et al (2008) proposed a CT-based compensator QA tool. In this study, we present a novel...
method for the compensator QA, providing for the first time the possibility of using proton beam. Proton beam was modulated to have a photon-like PDD so proton energy can be deposited linearly according to depth. Comparisons were made between coordinate information of compensator extracted from DICOM RT and proton imaging of compensator on the EBT film. We evaluate the agreement using mean absolute difference (MAD).

2. Materials and methods

2.1. Proton therapy system and beam current modulation (BCM)

At the Korea National Cancer Center, an Ion Beam Applications (IBA) PROTEUS 235 proton therapy machine has been operating since 2007. Our proton system features a 230 MeV proton cyclotron, a beam line, two gantry rooms, and a fixed room. Our cyclotron is 220 tons in weight, 210 cm in height, and 434 cm in diameter.

The spread-out Bragg peaks, which are typical of double scattering and uniform scanning treatment modes, are formed by integration of individual Bragg peaks with different ranges. The relative heights of these pristine Bragg peaks can be adjusted by controlling the incident proton beam current as a function of small wheel angle. A database containing the BCM is recorded for each hospital configuration; the values are determined by empirical measurement conducted by the manufacturer when the equipment is installed.

In this study we modified BCM to make photon-like proton beam. The individual Bragg curves were multiplied by the new weighting factors and the beam current intensity was modulated in synchronization with range modulation wheel rotation, providing a nearly linear slope of depth dose distribution (see figure 1). This depth dose distribution similar to that of x-ray attenuation was measured by ion chamber in the water phantom.

![Figure 1: Percent depth dose of a photon-like modulated proton beam](image)

2.2. Proton imaging of range compensator

Two proton range compensators were randomly chosen from patients who were treated with proton radiotherapy at our institution. The compensator matrix is produced within the calculation process in TPS (Eclipse; Varian Medical Systems, Salt Lake City, UT) and is then converted into a drilling pattern based on drill bit definitions found in a special milling machine parameter. The proton compensators were made of methyl methacrylate and manufactured using a milling machine (VCNC500; Cincinnati Lamb, Birmingham, England) with a drill of radius 2.5 mm.

Geometry information of each range compensator comes directly from the DICOM RT plan and was imported to MATLAB software (Mathworks, Natick, MA) (see figure 2). Maximum depth of
each compensator was 35.6 and 50.2 mm. Depth information in the z-axis were to be compared with optical density (OD) information of the gafchromic EBT film (International Specialty Products, Wayne, NJ). In order to make this comparison possible, step phantoms ranging from 4 mm to 50 mm in 2 mm increments were irradiated by photon-like proton beam on the EBT film to generate OD-depth calibration curve as a lookup table.

After converting OD to given depth, six flat region was chosen and the mean absolute difference (MAD) was calculated to quantify the similarity of chosen area between DICOM and film images:

\[
MAD = \frac{1}{mn} \sum_{p=1}^{m} \sum_{q=1}^{n} |I_{DICOM}[p,q] - I_{EBT}[p,q]|
\]  

(1)

The \( m \) and \( n \) is maximum pixel number of x-axis and y-axis. \( I_{DICOM} \) and \( I_{EBT} \) are the \( pq \)th depth for the DICOM and EBT.

![Figure 2: Two range compensators extracted from RT DICOM.](image)

![Figure 3: OD-depth calibration curve obtained from step phantoms](image)

3. Results
Converted film images and chosen flat areas for comparison were shown in figure 4. Calculated MADs over chosen areas were listed in table 1.
Figure 4: Two range compensators image converted from OD to depth

Table 1: Depth over the selected area and calculated MAD.

| Region  | a   | b   | c   | d   | e   | F   | a   | b   | c   | d   | e   | f   |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| MAD (mm)| 0.7 | 1.0 | 0.2 | 0.6 | 0.1 | 0.8 | 0.3 | 0.1 | 0.8 | 0.9 | 0.3 | 0.7 |

4. Discussion
The purpose of the project was to conduct a feasibility study of alternate method for QA of proton range compensator. For evaluating the precision of manufactured compensators we developed QA method using photon-like proton beam. Our comparison using MAD showed good agreement within 1 mm. The MAD over the high gradient area was over 1 mm, but we in this study focused on evaluation of precision of compensator depth over the flat region with low gradient. This proton-based QA method is expected to provide more reasonable precision with further correction of scattering effect on proton imaging.

5. Reference
[1] Li H et al 2010 Phys. Med. Biol. 55 6759-81
[2] Smith A R 2006 Review: proton therapy Phys. Med. Biol. 51 491-504
[3] Yoon M et al 2008 Med. Phys. 35 3511-7