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Dosimetric Impact of Ti Mesh on Proton Beam Therapy

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When a high density metallic implant is placed in the path of the proton beam, spatial heterogeneity can be caused due to artifacts in three dimensional (3D) computed tomography (CT) scans. These artifacts result in range uncertainty in dose calculation in treatment planning system (TPS). And this uncertainty may cause significant underdosing to the target volume or overdosing to normal tissue beyond the target. In clinical cases, metal implants must be placed in the beam path in order to preserve organ at risk (OARs) and increase target coverage for tumors. So we should introduce Ti-mesh. In this paper, we measured the lateral dose profile for proton beam using an EBT3 film to confirm dosimetric impact of Ti-mesh when the Ti-mesh plate was placed in the proton beam pathway. The effect of Ti-mesh on the proton beam was investigated by comparing the lateral dose profile calculated from TPS with the film-measured value under the same conditions.

Keywords: Ti-mesh, Proton, Artifact, TPS, EBT3 film

Introduction

Proton therapy has several advantages over conventional radiation therapies using a clinical linear accelerator (CLINAC). For example, the distal fall-off in depth dose distribution and high-energy deposition in the Bragg peak area assure little irradiation damage on normal tissues except for the tumor. Although proton therapy makes it possible to concentrate the dose on a tumor, there exist various uncertainties in proton treatments; setup uncertainties, patient motion uncertainties, range uncertainties related to tissue heterogeneities.[1)] Especially, if a high density metallic implant is placed in the path of the proton beam, spatial heterogeneity can be caused due to artifacts in three dimensional (3D) computed tomography (CT) scans. These artifacts result in range uncertainty in dose calculation in treatment planning system (TPS), as causing fewer signals to the detector and much image loss to which X-ray is absorbed more in the high density material region than in the normal region during the CT scan.[2,3)] Eventually, this uncertainty may cause significant underdosing to the target volume or overdosing to normal tissue beyond the target.[4)] Therefore, during actual patient treatment, it is recommended to avoid placing metal implants in the proton beam path. However, in clinical cases, metal implants must be placed in the beam path in order to preserve organ at risk (OARs) and increase target coverage for tumors. So we should introduce Ti-mesh. Titanium mesh implants are clinically appealing as they are strong, light-weight, foldable and magnetically and biologically compatible. In addition, Ti-mesh has been studied in several groups to show much less artifact on CT scan than other high-density metallic implants.[5)]

In this paper, we measured the lateral dose profile for proton beam using an EBT3 film to confirm dosimetric impact of Ti-mesh when the Ti-mesh plate was placed in the proton beam pathway. The effect of Ti-mesh on the proton beam was investigated by comparing the lateral dose profile calculated from TPS with the film-measured value under the same conditions.

Experimental Methods

Lateral dose profiles for proton beam are measured using EBT3 film in solid water phantom (30 cm×30 cm^2) to study dosimetric impact of Ti-mesh on proton beam therapy. The proton beam facility used in the present work was the Ion Beam Applications (IBA, Louvain-La-Neuve, Belgium) cyclotron PROTEUS 235, located at the National Cancer Center of Korea. The beam energy was 165 MeV double-scattering (DS) proton beam with a range (*R*) of 8.09 cm and a spread out bragg peak (SOBP) of 5.33 cm. As shown in Fig. 1, Ti-mesh with 0.6 mm thick and 10.1×9.8 cm^2 area was placed at depth 5 cm phantom and films were respectively arranged at depths of 0, 5, 10, and 30 mm based on the mesh. A 200 cGy DS proton beam was irradiated by changing the gantry angle to 0, 30 and 60 deg. To compare the difference of dose profile with and without Ti-mesh, the proton beam was irradiated under the same conditions without loading the Ti-mesh. When a proton beam is irradiated on an EBT3 film, quenching effect occurs at the Bragg peak, and the output tends to decrease by 20%.[6,7] As absolute dose analysis with the results calculated by TPS is impossible, so we should make a relative comparison analysis. The films were scanned using an Epson Expression 1100 XL scanner (Epson America Inc, Long Beach, CA, USA) and analyzed with RIT113 ver. 5.2

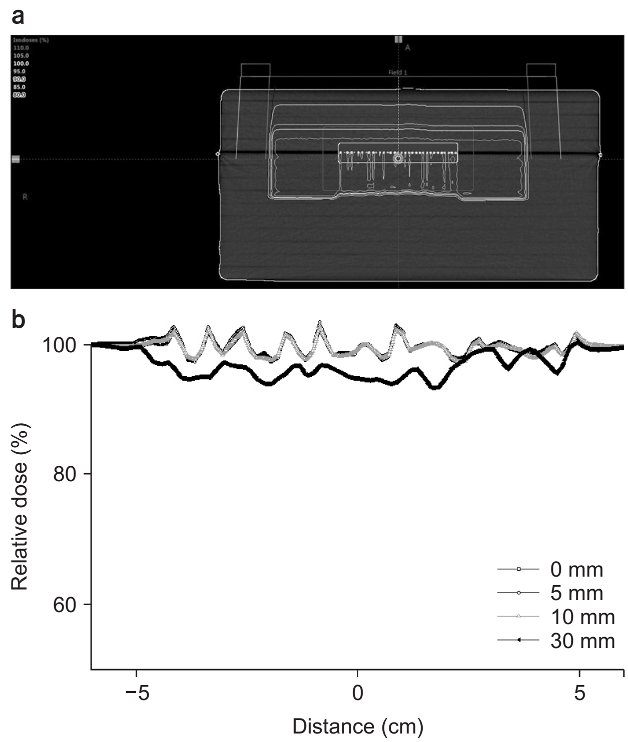

Fig. 2. (a) Phantom study on the effects of Ti-mesh on DS proton dose in TPS; (b) lateral dose profiles depending on depth calculated by proton convolution algorithm in TPS.

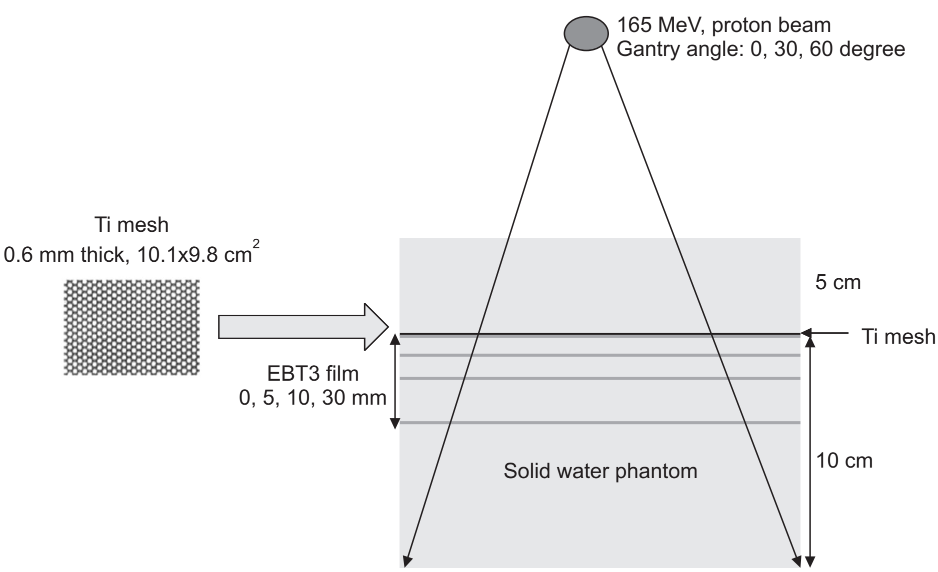

Fig. 1. The schematic of experiment setup for lateral profile measurements.

software (@2017, USA).

The Phantom Study in TPS System

A phantom system, which was set up to measure the lateral dose profile of the film, was scanned by our CT scanner and the CT images were imported into the Eclipse (Varian Medical System Inc.) TPS system. As shown in Fig. 2a, the proton beam under same conditions was placed to the phantom imported to the TPS system. CT was scanned on an extended scale at 2 mm slice thickness using a Siemens Sensation Open CT scanner (Siemens Medical Solutions USA, Inc., Malvern, PA, USA). In case of normal CT, the CT HU number is between -100 and +2000, but as the CT HU value is much larger for high density materials, it need to scan to an extended scale so that entire image can be seen. And since our CT scanner can be scanned with the IMAR version, the CT reconstruction algorithm is applied to the default value to improve the image quality by correcting the CT artifact caused by the mesh. Using the proton convolution superposition (Eclipse version 10) algorithm, the lateral dose profiles were calculated with 1 mm grid size. The proton convolution superposition algorithm inputs the characteristics of the actual measured proton beam into beam data tab of TPS system and calculate the dose by making a mathematical beam modeling using a virtual source, based on the data.

Results

Fig. 2b shows lateral dose profiles depending on depth calculated by proton convolution algorithm in TPS. The profiles according to depth show similar patterns at 0, 5, and 10 mm and dose reduction at 30 mm. The dose perturbation seen in the graph is considered to be the result of the effect of the patterned mesh structure when the proton beam passes through the Ti-mesh plate. The dose reduction phenomenon observed at 30 mm is described in the SOBP curve of Fig. 3a. Fig. 3a shows the SOBP curve of a double scattering proton beam with energy of 165 MeV. As shown in Fig. 2b, the portion corresponding to depth 30 mm from the Ti-mesh is matched with the end of the range in the SOBP curve of Fig. 3a and the relative dose of this part indicates 90%. Fig. 3b shows a graph of lateral dose profiles along the depth direction of the film at a gantry angle of 0 degrees. As shown in Fig. 3b, it can be seen that dose perturbation occurs in the mesh section in almost the same manner as in TPS. The irregular shape of the TPS is due to scattering by the mesh structure, so that the perturbation is more irregular depending on the depth. At 30 mm depth, dose reduction phenomenon occurs as well as TPS, which is exactly the dose profile result in TPS. When we measure other high-density materials such as Au markers, which are not actual mesh, in the beam path, they also tend to have a similar dose distribution over depth. When the distance between the mesh and the target is completely close, the effect is almost not exhibited. If the interval is more than at constant, the phenomenon such

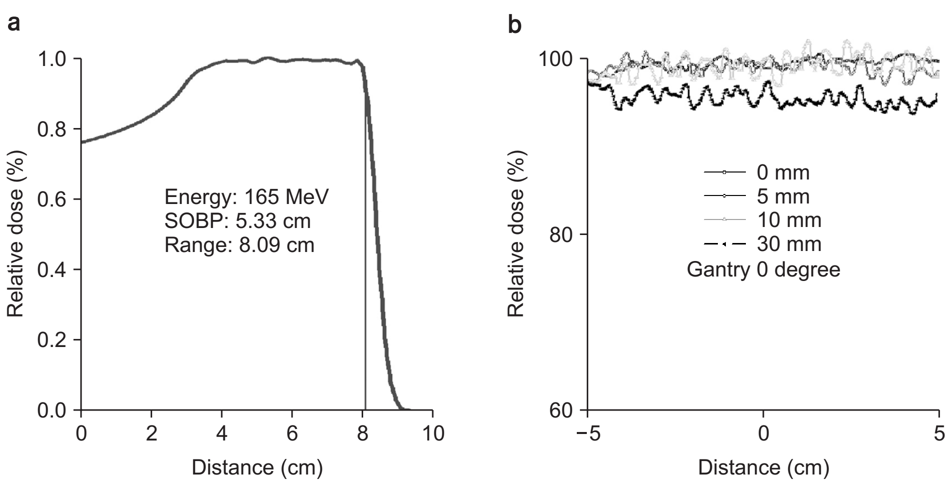

Fig. 3. (a) SOBP curve in 165 MeV DS proton beam; (b) lateral film dose profile measured depending on depth at gantry angle 0 degree.

as scattering appears well. Fig. 4 is a graph showing the difference in Dose distribution with and without Ti-mesh. The data showed the largest effect of dose perturbation at depth 1cm from mesh plate in actual film measurement. So it was compared based on depth 1cm. The average relative dose was 100.31% and the standard deviation was 0.32 when the mesh was present. The mean relative value was 100.12% and the standard deviation was 0.11 when there was no mesh. Therefore, it was confirmed that Dose perturbation phenomenon clearly appears when Ti-mesh is placed. Fig. 5 is a graph comparing the lateral dose profile calculated by TPS and the film measured along with gantry angle at depth of 1 cm. As shown in the graph, although there is a relative difference in the number of perturbation oscillations due to the scattering effect along the beam direction, it was confirmed that the overall dose distribution and vibration type match each other.

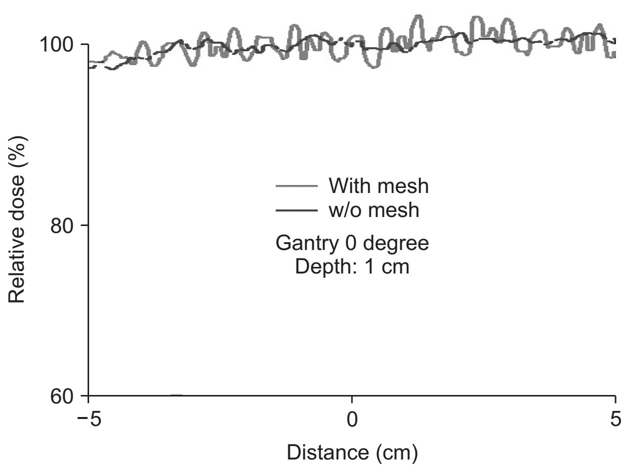

Fig. 4. Lateral dose profile at the middle of the SOBP with and without the mesh plate at depth 1 cm in film measurement.

Discussion and Summary

In this study, we investigated the dosimetric effect of Ti-mesh on the proton beam by measuring the lateral dose profile of the DS proton beam using EBT3 film and comparing the result with the calculated value in TPS. Previous studies have reported that when high-density metal implants are used in radiation therapy, underdosing or overdosing on tumors in dose calculation at TPS can be caused due to range uncertainty by artifacts during CT scans. And Ti-mesh also has been studied to show much less artifact in CT scan than conventional photon studies. Therefore, we should need to confirm how accurate the dose calculated by TPS when using proton therapy with Ti-mesh in actual treatment, and compared with the measured lateral dose profile using film.

Our experimental results showed no dose reduction in the Ti-mesh region and showed a dose profile very similar to that of TPS. Of course, in the case of films, the absolute dose can't be compared, so we can't make a quantitative comparison with the TPS results. In order to make a more quantitative comparison, we try to compare the exact range error by measuring the percentage depth dose (PDD) for proton beam. As it is difficult to measure the PDD with a film, we are currently fabricating a system for

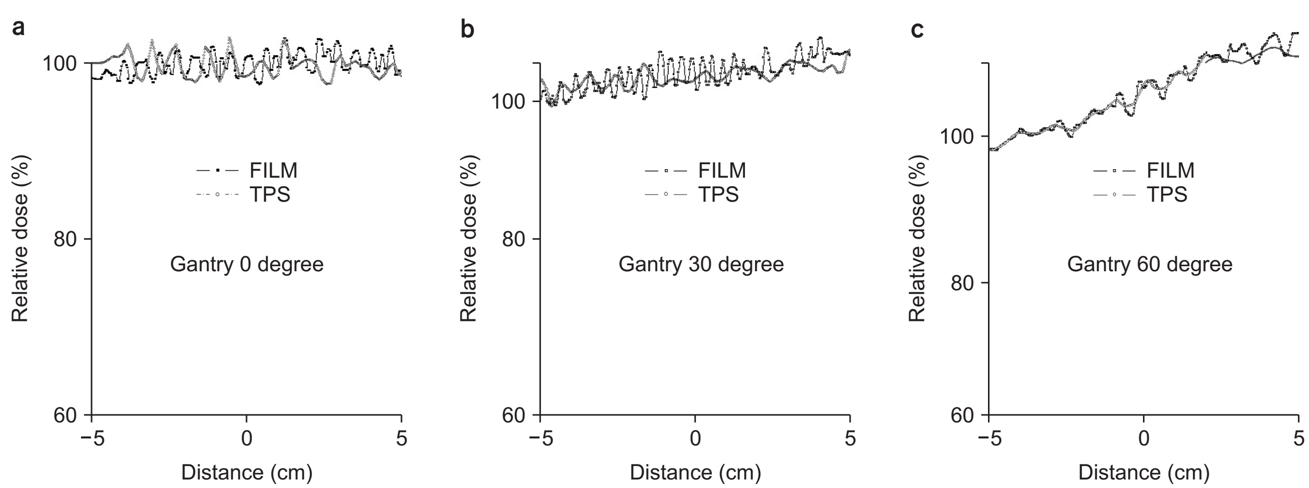

Fig. 5. Comparative analysis between dose profiles of film and TPS depending on gantry angle at depth 1 cm.

measuring the PDD using an ion chamber by placing a Ti-mesh on a 3D water phantom. We will also have a study on the dosimetric impact of Ti-mesh through comparison for results of three methods such as TPS, chamber measurement and theoretical calculation through Monte Carlo simulation. This study is a preliminary experiment for further study, and we think that Ti-mesh showed the possibility of clinical application in proton therapy.

Acknowledgements

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Conflicts of Interest

The authors have nothing to disclose.

Availability of Data and Materials

All relevant data are within the paper and its Supporting Information files.

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