HIROSAKI UNIVERSITY

Radiation Environment and Medicine 2018 Vol.7, No.1 42–46

REM
Radiat Environ Med

Note

Quantitative Evaluation of Intensity Modulated Radiotherapy (IMRT) Dose Distribution via Intensity Modulation Calculated through the Filtered Back Projection (FBP) Method

Kazuki Nomura[1], Kouichi Shioya[2], Fumio Komai[3], Shingo Terashima[4] and Yoichiro Hosokawa[4]*

[1]*Department of Imaging Center, St. Marianna University School of Medicine Hospital 2-16-1 Sugao, Kawasaki, Kanagawa 216-8511, Japan*
[2]*Department of Radiological Technology, Odate Municipal General Hospital. 3-1 Toyomachi, Odate, Akita 017-8550, Japan*
[3]*Department of Radiological Technology, Hirosaki University Hospital. 66-1 Hon-cho, Hirosaki, Aomori 036-8564, Japan*
[4]*Department of Radiation Science Hirosaki University School of Health Sciences. 66-1 Hon-cho, Hirosaki, Aomori 036-8564, Japan*

Received 21 July 2017; revised 2 October 2017; accepted 16 October 2017

Intensity-modulated radiotherapy (IMRT) involves dose-intensity optimization for inverse planning and creates an ideal dose distribution. Optimization calculation is necessary to avoid iterative calculation, which is time consuming. This study aimed to prove the theoretical possibility of planning IMRT using filtered back projection (FBP).

In a previous study, we created an FBP program using Excel. The program was used for image reconstruction to obtain the desired virtual cancer shape, and back projection data were obtained during reconstruction. IMRT dose distribution was achieved by transplanting these back projection data as beam intensity to the treatment planning system. In the previous study, the dose distribution was not evaluated with a quantitative index. Therefore, to evaluate the dose distribution of this method through a quantitative index, the projection angles during image reconstruction were planned in 18 and 36 directions, and the dose-volume histogram (DVH), homogeneity index, and conformity index were compared. The results of the DVH graph of projection in 18 and 36 directions confirmed that the larger the projection angle, the higher the reproducibility of the original image. Creating a dose distribution with high dose concentration was possible.

At present, IMRT is planned using an optimization algorithm. However, results of the current study show that the beam intensities of IMRT can also be determined by processing only the image reconstruction using FBP in terms of dose distribution evaluation through quantitative indicators.

Key words: intensity modulated radiation therapy (IMRT), optimization, filtered back projection (FBP), inverse planning, reconstruction algorithm

1. Introduction

Intensity-modulated radiation therapy (IMRT) has recently become increasingly popular as an advanced radiotherapy technique[1, 2]. IMRT is the advanced form of external beam irradiation and can administer dose freely

*Yoichiro Hosokawa: Department of Radiation Science, Hirosaki University School of Health Sciences. 66-1 Hon-cho, Hirosaki, Aomori 036-8564, Japan
E-mail: hosokawa@hirosaki-u.ac.jp

even to targets of complicated shapes. IMRT is expected to improve treatment outcomes and better mitigate complications compared with conventional external irradiation method. However, if treatment planning and quality control are not performed properly, the treatment outcome may decrease and adverse events will increase[3]. To perform IMRT, inverse planning based on the dose constraints of planning target volume (PTV) and organs at risk (OAR) is necessary. However, in inverse planning, reaching the ideal treatment plan through optimization calculation is time consuming[4, 5].

Dose calculation using the filtered back projection (FBP) principle was developed for inverse planning of early radiotherapy[6]. The FBP dose calculation method has been used to develop an inverse treatment planning algorithm for iterative filtered back projection (IFP)[7]. Determining the proper beam intensity is time consuming[7]. We devised a method to determine the dose intensity as a slit irradiation of the IMRT via only the image reconstruction process without calculating the dose intensity through a repetitive method. When the dose is calculated with treatment planning system (TPS) using the dose intensity method created by us, a dose distribution with high concentration can be obtained, although it is a visual evaluation of only one section[8]. The density is adjusted, but the dose distribution becomes nonuniform unless the original image density is manually adjusted and the image density is reconstructed during FBP processing. Further, another problem is that the dose intensity data have to be inputted manually to the TPS at the time of transplantation. If this method is established, optimization calculation for inverse planning can be hastened.

In the present study, the dose distribution determined via our method for dose intensity optimization was evaluated through the dose-volume histogram (DVH), homogeneity index (HI), and conformity index (CI) of the dose distribution for the three-dimensional PTV shapes.

2. Material and methods

2.1. Overview of image reconstruction program

Although the FBP method of our technique has been shown earlier, it is discussed in detail here[8]. In accordance with the image reconstruction theory of the FBP method, the program for image reconstruction of the original image inputted to a cell with a matrix size of 64 × 64 was created using Microsoft Excel 2010 (Microsoft, Redmond, USA). This program is composed of a Visual Basic for Application, which is Excel's programming language. Next, a virtual shape of prostate cancer was entered into Excel cell as PTV (Fig. 1 a-b). The multileaf collimator (MLC) of Linear Accelerator (CLINAC iX) (Varian Medical Systems, Palo Alto, USA) has a minimum width of 5 mm. PTV was entered assuming that the pixel size is also 5 mm square. The primary reason for setting the size in the body axis direction to 5 mm is because of the limited number of the TPS, which will be described later. In addition, this method required 36 ports per slice, and as the number of slices increased, the calculation speed of the TPS slowed down, and the stability of the software declined.

In this program, calculating with a pixel size of 5 mm or less is possible using Excel; the smaller the pixel size, the better the reproducibility of the reconstructed image. However, in the current program, the intensity modulation data must be transplanted to the TPS as described in method 2-2. Beam intensity data are expressed using MLC. In addition, the grid size at the dose planning stage where intensity modulation was implanted to the TPS was set to 4 mm to shorten the calculation time. In the FBP method, each cell has the concept of density, and this value is added as the projection increases[9].

In this program, the density of the original image was calculated as 1. For transplantation to the TPS, negative values were cut to the sinogram after filtering dose intensity was divided into three-stage intensity back projection was performed; and a reconstructed image was obtained on the program. The reconstructed image obtained through the first reconstruction did not achieve a satisfactory dose distribution due to uneven density. Therefore, the density adjustment process was modified. Thereafter, the reconstructed image was again inputted as an original image on the program after concentration adjustment, and FBP processing was performed. When this density adjustment work was repeated and the reconstructed image showed a uniform density distribution, the back projection data used to acquire the reconstructed image were obtained. Two types of 18 projections and 36 projections were obtained for the back projection data.

2.2. Transplantation of back projection data to TPS

First, CT scan was performed on the IMRT dedicated phantom RT-3000-New. The photographing conditions were as follows: 120 kV X-ray tube voltage, 700 mA tube current, 19.57 s photographing time, and 1.25 cm slice thickness.

In the previous study, data were only verified using the TPS (Pinnacle 3, Version 8.0 m, Hitachi Medical Corporation, Tokyo, Japan). In the present study, data were verified using the TPS (XiO, Elekta, Stockholm, Sweden) with the aim of confirming whether a good dose distribution can be drawn even if the treatment planning device is different.

Phantom data were transferred to the TPS, and a virtual prostate shape was outlined at the center of the

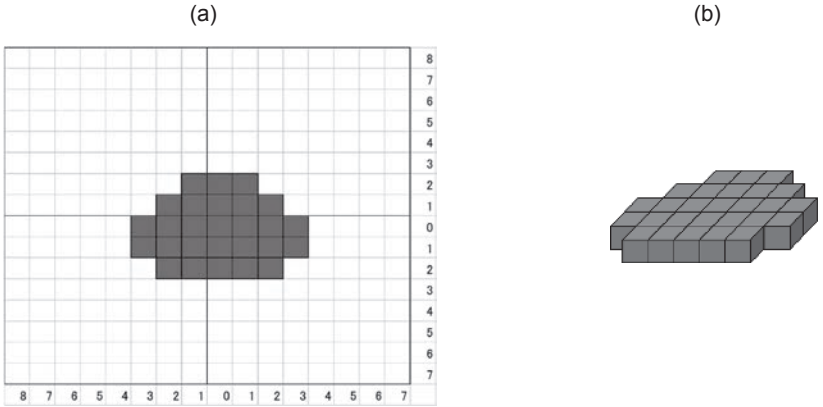

Fig. 1.
(a) The virtual shape of prostate cancer created by combining a 5-mm side cube into an Excel program. The intersection of the bold line center was made the isocenter.
(b) 3 dimensional view of virtual prostate cancer shape in (a).

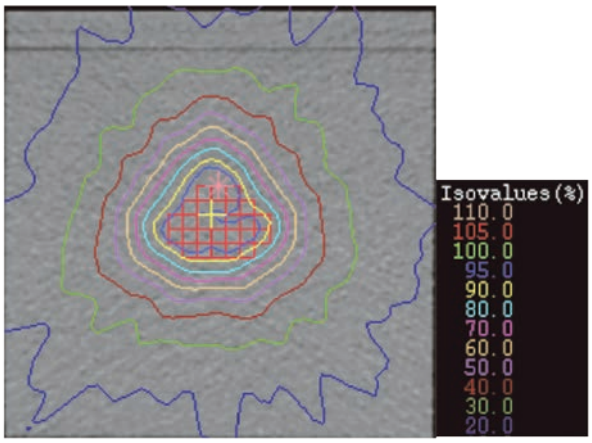

Fig. 2. The dose distribution on the TPS as determined through isodose. Curves at the isocenter cross-section in the direction of projection angle 36.

phantom. Afterwards, back projection data were transplanted to the treatment planning device as intensity modulation data obtained during PTV image reconstruction program. However, the maximum number of ports that can be used by the TPS XiO is 99, and entering 100 ports or more is impossible. As such, we planned to input 108 ports using real numbers by using the function to divide one port into 3 segments.

To create a slit using the MLC shape, the linear accelerator collimator was rotated 90°, and a slit was made via the MLC to achieve intensity modulation. Superposition method was used as calculation algorithm, and the X-ray energy is 10 MV. The dose at treatment planning was set so that the value of D95 was 74 Gy. The margin in the body axis direction with PTV by MLC after implantation in TPS was set to 5 mm. For jaw opening, we set the minimum setting in TPS to 15 cm × 15 cm because the virtual target size is extremely small.

2.3. Quantitative evaluation of dose distribution

We quantitatively evaluated the dose distribution through this method not only for the dose distribution of only one cross-section but also for three-dimensional PTV shape. In the case of only one section, the evaluation was aimed to confirm the DVH, HI, and CI, which could not be evaluated previously.

The DVH, HI, and CI were calculated for cases in which 18 plans were planned for the same PTV and 36 plans were planned, and the results were compared. When planning at 18 ports, data were collected at intervals of 20° with those directly below as 0°. When planning at 36 ports, data were collected at intervals of 10°, with those directly below as 0°.

3. Results and discussion

Dose distribution of the 36 port isodose curves at the

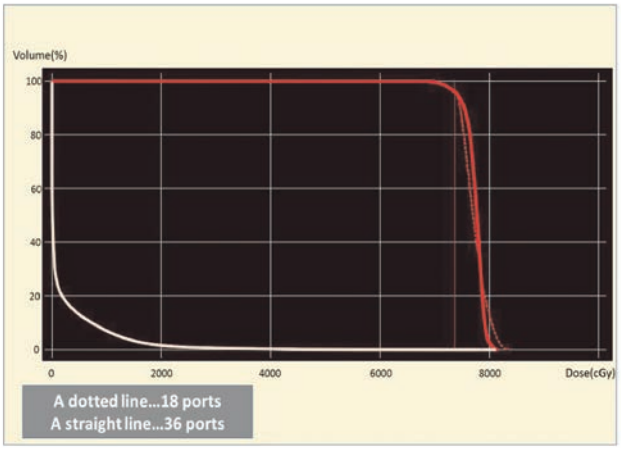

Fig. 3. DVH in projection with 18 and 36 directions. The DVH curve of PTV planned with 36 projections. The DVH curve of PTV planned with 18 projections.
(A straight line) The DVH curve of PTV planned with projection number 36
(A dotted line) The DVH curve of PTV planned with projection number 18

isocenter cross-section is shown in Figure 2. The results confirmed that satisfactory dose distribution can be obtained even if the TPS is different. Therefore, it was confirmed that the FBP program normally operates and the beam intensity is calculated with the calculation time of image reconstruction degree. The same irradiation condition and the DVH data of 18 and 36 projections for PTV are shown in Figure 3. The DVH data confirmed a strong dose concentration in PTV.

Based on analysis of dose administered via DVH, when dose was planned so that the value of D95 would be the same for 18 and 36 projections, the average dose to PTV was 7713 cGy at 18 ports and was 7741 cGy at 36 ports. Although the average dose had almost no difference, the minimum and maximum doses were higher by approximately 200 cGy at 18 ports (Table 1). Because this technique uses the FBP method, superimposition irradiation via various MLC shapes becomes possible as the number of ports to be irradiated becomes larger, and the overlapping of the flux is reduced. Our method also shows the HI and the CI, which are factors for evaluating dose distribution uniformity in PTV and dose convergence (Table 1).

HI is an indicator of dose uniformity for PTV, which is calculated as HI = Dmax/Dmin. The closer the value is to 1, the higher is the dose uniformity. CI was calculated as CI = volume surrounded by prescribed dose in PTV/PTV, although many definitions are available. The closer the CI is to 1, the better the dose concentration[10-11]. No significant difference was found between CI and HI in the projection with 18 and 36 directions. However, from the DVH graph of the 18 and 36 projections, 36 ports were quantitatively confirmed to obtain a better dose distribution compared

Table 1. Dose, volume, and dose convergence index in the projection angle with 18 directions and the projection angle with 36 directions

	PTV-18port	PTV-36port
Total Volume(cc)	3.38	3.38
Inclusion(%)	100	100
Minimum Dose(cGy)	6811	6694
Maximum Dose(cGy)	8343	8148
Mean Dose(cGy)	7713	7741
D95(cGy)	7359	7359
Homogeneity Index(HI)	1.225	1.217
Conformity Index(CI)	0.962	0.961

with 18 ports. Creating a dose distribution with high dose concentration with a large number of projections was thought to be possible. This shows that the intensity modulation data of IMRT can be calculated by this method without using the conventional optimization calculation using the algorithm for dose intensity calculation. However, in order to enable high-speed rendering of the dose distribution, there are problems of manual density treatment and automation of data transfer to the treatment planning apparatus. Therefor we need to establish the standard density level in this method, and make the program to transfer data of dose distribution to TPS in the future.

4. Conclusions

The results of this study confirmed through quantitative index that a good dose distribution can be created using intensity modulation data of IMRT determined via the FBP method. Although this method has several problems, such as concentration adjustment and automation of transplantation to the TPS, if it is established, the computation time itself is only about reconstruction time of CT image. Therefor the tumor that continues to change during treatment can be accurately irradiated because the calculation time is short.

Conflict of Interest Disclosure

The authors have no conflict of interest directly relevant to the content of this article.

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