

The lateral shift effect of gamma index evaluation on tomotherapy

Yosi Sudarsi Asril¹, Nuruddin Nasution², Wahyu Edy Wibowo², and Supriyanto Ardjo Pawiro¹

¹*Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Indonesia, Depok, West Java, 16424, Indonesia*

²*Department of Radiotherapy, Cipto Mangunkusumo General Hospital, Jakarta, 10430, Indonesia*

E-mail: yosisudarsi@gmail.com

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Abstract: Fourteen patients with different cases have been planned and treated using helical Tomotherapy HI-ART system. To investigate the lateral shift effect on gamma index, the planning verification was evaluated for a point dose and a fluence dose measurement using ion chamber and Gafchromic EBT3 film, respectively. As a result, the difference between a measured and calculated point dose was under 3% for all interest organs, which account for $1.46 \pm 0.71\%$ (parotid), $1.97 \pm 0.56\%$ (pelvis and abdomen), $2.27 \pm 0.24\%$ (brain), $1.56 \pm 0.51\%$ (nasopharynx), and $1.43 \pm 1.3\%$ (breast). In addition, Gamma index criteria used to evaluate fluence dose was 3mm (distance-to-agreement) and 3% (dose-difference) with 90% passed rate. Overall, the results, found in this study, shows that a lateral shift of the patient table resulted in an error beyond an acceptable tolerance if the table was shifted at more than 3mm. Gamma index criteria, then, is met if the lateral shift was within 3mm.

Keywords: *delivery quality assurance, gamma index, tomotherapy*

1. Introduction

Helical TomoTherapy HI-ART (TomoTherapy, Inc., Madison, WI) having a purpose of delivering Intensity Modulated Arc Therapy (IMRT), is an advanced technique of radiotherapy intended to deliver a highly conformal dose distribution to a target organ.¹ This system incorporates Megavoltage Computed Tomography (MVCT) system that used to verify patient position, reduce set-up errors, and allow an intended volume to gain accurate dose before the treatment. The shift of patient table, in Tomotherapy, has a small order (10^{-3} cm) compared with the patient table in a typical Linear Accelerator machine, which account for two order of magnitude (10^{-2} cm). To determine the table shift during patient positioning, MVCT incorporated in helical tomotherapy system is used to image patient before a radiation is delivered. Lin *et al.*² shows that the lateral shift, in tomotherapy treatment, in millimeter range resulted the variability was significantly after patient underwent MVCT. Then, patient positioning is of paramount importance to achieve the dose delivery accuracy such that it is necessary to determine the shift tolerance allowed in positioning the table during the helical tomotherapy treatment.

Patient-specific DQA is a pre-treatment verification program for a complex dynamic delivery technique in Tomotherapy required to ensure an accuracy of the radiation dose delivery³. The DQA becomes necessary in a helical tomotherapy treatment as the use of IMRT can generate a hot and cold spot in the composite dose due to the steep dose gradient in the treated volume. The pre-treatment evaluation of the radiation dose delivery can be performed by means of the evaluation of gamma index and distance-to-agreement (DTA) on the registered dose distributions between measured and calculated. The latter parameter on the evaluation process is described as the nearest distance between a point dose of a reference dose and that of the same amount of dose on the compared dose distributions, and a percent dose difference (ΔD) is defined as absolute dose variation between two points at a calculated and measured

dose.⁴ Low *et al.* developed a technique which simultaneously incorporates both (ΔD) and DTA values into the quality index, called gamma (γ).⁵ The quality index demonstrates the difference between the calculated and measured dose relative to the acceptance tolerance.

The acceptance tolerance of gamma index for film evaluation varies from user-to-user. The ICRU 42 report recommended that a percent dose difference and a distance-to-agreement (DTA) are 2% and 2 mm, respectively.⁶ In addition, a 3mm of DTA and 3% of a percent dose difference were used by Pelagade *et al.*⁴ to evaluate gamma index value for film evaluation while Van Dyk *et al.*⁷ suggested a higher tolerance of DTA, which is 4 mm, compared with tolerance used by Pelagade *et al.* and 3% of a percent dose difference. The most recently-published report, Winkler *et al.*⁸ recommended to use a 3mm of DTA and 5% of the percent dose difference due to finding satisfying dose conformity. In this study, we evaluated the gamma index value of the gafchromic EBT3 film using the acceptance tolerance proposed by Pelagade *et al.* and the acceptance tolerance for a point dose measured using ion chamber is $\pm 3\%$ as recommended on literature.

To our knowledge, there is a paucity of the information in term of the lateral shift effect of the patient table in gamma index evaluation such that, in this study, we study about the effect of the lateral shift of patient table during a helical tomotherapy treatment and determine the shift tolerance allowed in order not to result in an inaccuracy of dose delivery to patient.

2. Materials and methods

Table 1 shows information about fourteen treatment plans studied in this research. The information describes prescription dose, number of fraction, field width, pitch, and PTV volume. Fourteen treatment plans listed in Table 1 comprise three pelvis and abdomen (P&A) cases, two parotid (P) cases, three brain (BR) cases, three breast (B) cases, and three nasopharynx (N) cases. All the treatment plans, between the measurement and calculation on TPS, were compared and evaluated for point dose and fluence dose, and all the evaluation was based on the gamma index value.

The measurement of a point dose and a fluence dose was performed using a specially-designed solid-water phantom, called Cheese Phantom. The cheese phantom is cylindrical phantom having 18 cm in length and 15 cm in radius. This phantom comes apart in two semi-cylinders such that the film can be placed along the central axis of the phantom. Additionally, the cheese phantom has holes for placing the ion chamber to measure the point dose at an interest point. The fluence dose, in this study, was measured using Gafchromic EBT3 film and the point dose was measured with exradin A1SL ion chamber (Standard Imaging, Middleton, WI). The use of the exradin A1SL is a good choice for the measurement of a point dose in high dose gradient due to having a small active volume (0.056 cm^3). For fluence dose evaluation between the measurement and calculation on TPS, gamma index value was taken from the comparison of two dose distributions measured using Gafchromic EBT3 film. The agreement criterion for the fluence dose measurement was 3 mm of DTA, 3% of a percent dose difference, and 90% of passing rate.

2.1. Patient-specific DQA planning and delivery

A patient-specific DQA for fourteen treatment plans was generated using DQA station analysis software integrated with tomotherapy treatment planning system (Tomo^{HD} System). DQA station software performed CT data set of the cheese phantom and it involved the forward dose calculation on patient treatment plans. The DQA plan was scaled so that the delivered dose ranged to make the plan fall within the linear area of the calibration curve⁹. DQA plans were formed by transferring one slice of patient planning in the middle of target volume into a cheese phantom and recalculating the dose. So that we know the calculated dose and compare the calculated dose with measured dose. Moreover, DQA station software can be used for aligning the cheese phantom using the red lasers for positioning.

After the DQA plans were created, the measurement was ready to perform, and the cheese phantom was ready to set up. The cheese phantom, then, was imaged using MVCT to correct the phantom position before the measurement was carried out. The image generated from MVCT was registered with the original CT data set of the DQA phantom to generate the X-Y-Z position error. After the MVCT was done on the phantom and the new X-Y-Z position of the phantom was generated, then the measurement can proceed.

2.2. Dosimeter preparation

Prior to the fluence dose measurement using gafchromic EBT3 film, the film was calibrated to generate the calibration curve of the film. The calibration was performed by irradiating the film, which has been cut into a small square with a size of 5 x 5 cm². The dosimeter was calibrated using time which ranged from 1 to 60 seconds compared with dose in every second using 5 cm Virtual WaterTM slab, an Exradin A1SL ion chamber, and a 1 cm Virtual WaterTM slab to reproduce the setup. The gafchromic EBT3 film is at 1 cm depth and the ion chamber at 2 cm depth.

The calibration using ion chamber aimed to obtain an absolute dose value where the temperature and pressure parameters also affect the value of the dose. The result of the film calibration was analyzed using tomotherapy film analyzer software to obtain the calibration curve data by comparing digitized pixel value dos and the value (cGy) that has been treated.

2.3. Measurements

To evaluate the impact of the lateral shift to the gamma index evaluation, the measurement was varied in the lateral shift of the patient table. The lateral shift of 1 mm, 2 mm, 3 mm, 4 mm, and 5 mm from the isocenter was taken for the measurement. Point dose measurement was sampled from the patient treatment plan at a point in which the ion chamber was inserted into an appropriate hole. The ion chamber reading was recorded using TomoElectrometerTM.

Fluence dose measurements were measured using gafchromic EBT3 film. Prior to the film processing, the film was left for some period of time to develop after irradiation. After which, the film was scanned using VIDAR dosimetry Pro Advantage (VIDAR System Corporation, Herndon, VA) and analyzed using Tomotherapy Film Analyzer software.

2.4. Result Analysis

The evaluation of a point dose measurement was calculated by determining the percent discrepancy between a measured dose and a DQA calculated dose at a given point and can be calculated according to the following equation:

$$\%discrepancy = \left| \frac{D_{calculated} - D_{measured}}{D_{measured}} \right| \times 100\% \quad (1)$$

3. Results and discussion

3.1 Point dose measurement

Figure 2 shows the absolute percentage difference between the calculated and measured dose. The average percentage dose difference and standard deviation for all of the cases evaluated for each body site were; 1.46±0.71% for parotis, 1.97±0.56% for pelvis and abdomen, 2.27±0.24% for brain, 1.56±0.51% for nasopharynx, and 1.43±1.3% for breast. Based on the result, the standard deviation is much larger for breast cases due to dose gradient at the point.⁴ Furthermore, the point dose measurement using exradin A1SL resulted in a good agreement, which falls within the acceptance tolerance (±3%) between the measured and calculated dose. As a consequence, A1SL ion chamber is sufficient as a type of microchamber to measure the dose at high dose gradient.⁴

3.2 DQA fluence dose film measurement

The gamma index evaluation of fluence dose measurements is shown in Figure 3. The lateral shift below 2 mm in patient table can generate gamma index value within the passing rate criteria as demonstrated in Figure 3a dan 3b.

Table 2 and 3 show the average of gamma index percentage. In this table, it can be seen that the average of each case indicated the percentage is not giving a significant difference. The gamma index at positions 1 mm to 2 mm is still above 90%, but in a position of 4 mm to 5 mm, the gamma index percentage is less than the passing rate, whereas at 3 mm there are some cases which still included in the passing rate. While cases of brain and breast cases are not included.

Table 1. Plan information for 14 treatment plans of patient. The five different treatment listed are pelvis and abdomen (P&A), parotis (P), brain (BR), nasopharynx (N), and breast (B).

Plan Information	NC	RR	JK	DS	WJ	WT	CH	NW	OY	ES	LS	AS	DS	UM
Treatment sites	P&A	P&A	P&A	P	P	BR	BR	BR	B	B	B	N	N	N
Presc. dose (Gy)	78	46	46	66	66	60	40	60	50	50	50	70	70	70
Fraction	39	23	23	33	33	30	10	30	25	25	25	33	33	33
Field Width (cm)	2.5	5.02	5.02	5.02	2.5	1.05	1.05	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Pitch	0.43	0.43	0.43	0.43	0.43	0.30	0.18	0.30	0.40	0.287	0.287	0.30	0.28	0.28
Volume of PTV	229.9	1656.9	1310.1	585.8	89.2	172.4	26.9	352.9	786.2	581.4	606.5	858.7	1092.8	1703.1

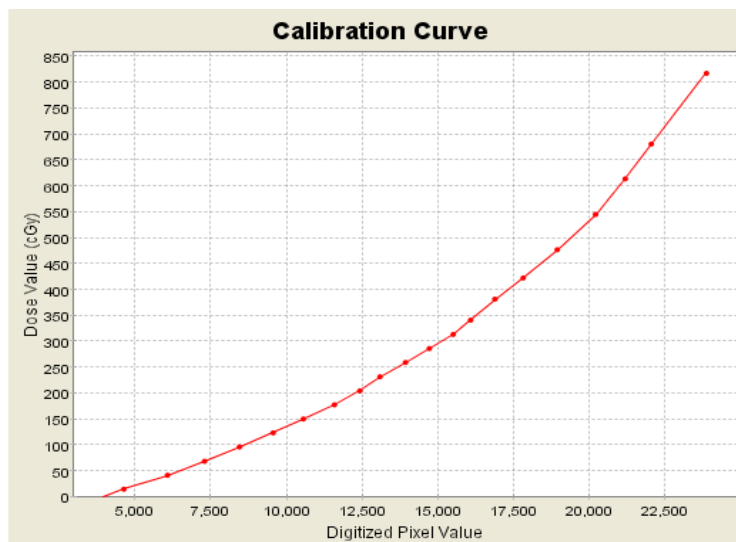


Figure 1. Calibration curve using gafchromic EBT3 film.

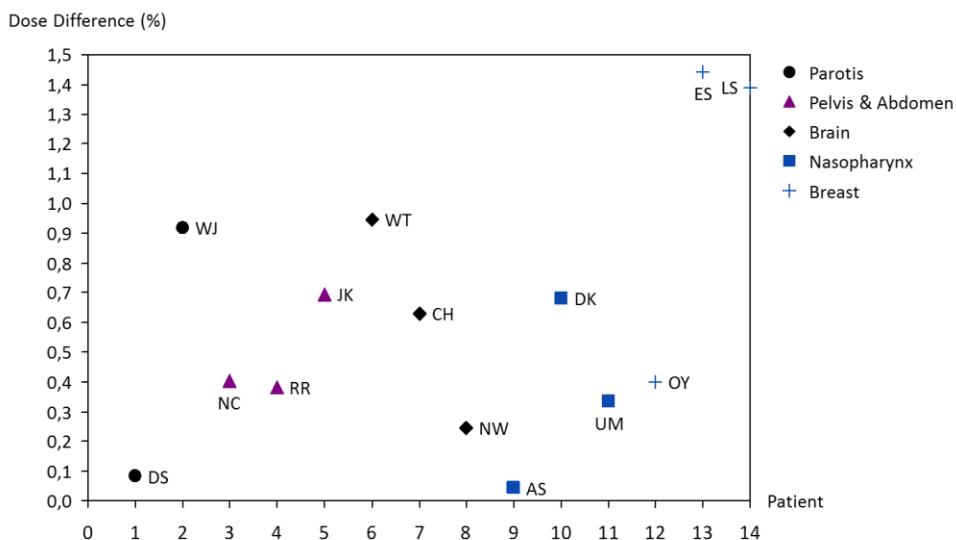


Figure 2. Dose difference (absolute) variation for 5 cases (14 patient)

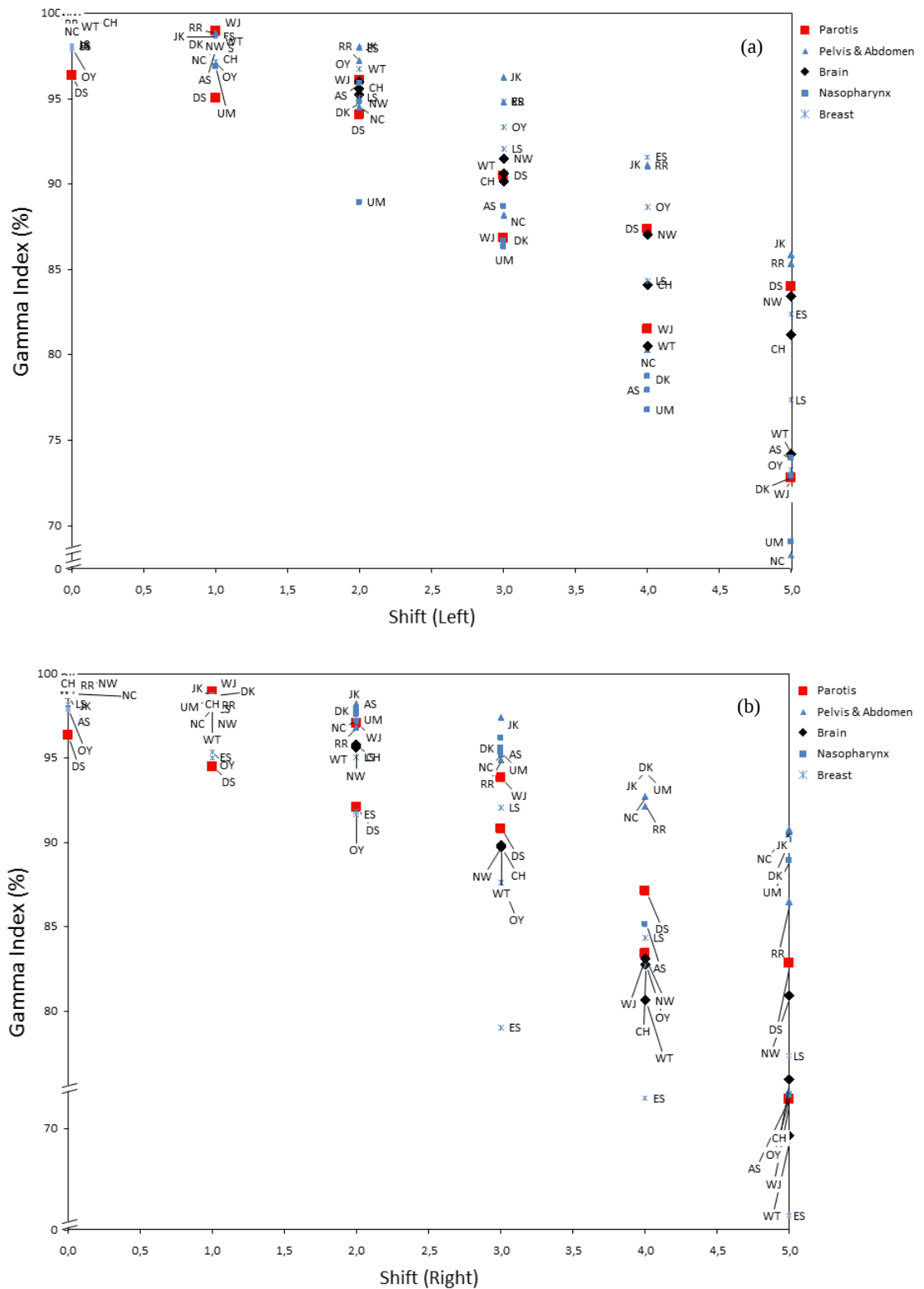


Figure 3. Gamma index analysis on (a) left and (b) right shift every 1 mm until 5 mm for all 14 patient of each site.

Table 2. The average of gamma index percentage in right shift of all patient cases

Shift	P&A	P	BR	B	N
0 mm	99.06%	97.94%	99.47%	98.03%	99.34%
1 mm	98.38%	96.73%	98.34%	96.10%	98.61%
2 mm	97.43%	94.58%	95.68%	92.81%	97.56%
3 mm	95.88%	92.33%	89.76%	86.19%	95.71%
4 mm	93.07%	85.25%	82.15%	79.57%	91.31%
5 mm	89.28%	77.26%	75.43%	71.39%	83.69%

Table 3. The average of gamma index percentage in left shift of all patient cases

Shift	P&A	P	BR	B	N
0 mm	99.05%	97.93%	99.46%	98.04%	99.34%
1 mm	98.44%	96.98%	98.16%	97.90%	97.77%
2 mm	96.58%	95.08%	95.58%	96.54%	93.21%
3 mm	93.07%	88.65%	90.74%	93.38%	87.22%
4 mm	87.46%	84.40%	83.85%	88.17%	77.76%
5 mm	79.04%	78.35%	79.54%	77.62%	71.94%

4. Conclusion

The results showed that the average percentage dose difference and standard deviation for all of cases evaluated for each cases is less than 3%. The result of gamma index measurements evaluation is less than passing rate with less than 90% percentage on patient table shift ≥ 3 mm. The result from right shift shown the failure rate of gamma index is 0%-0.72%, 2.05% -12.74%, 0.24%- 14.57%, 3.81%-18.61%, 0%-6.31% for P&A, P, BR, B, and N cases respectively. While the failure rate result from left shift of gamma index is 2.54%-10.962%, 1.35%-11.65%, 6.15%-10.46%, 1.83%-12.36%, and 2.78%-18.06% for P&A, P, BR, B, and N cases respectively. All the results showed that the shift that still has a value of acceptance on gamma index is within 2 mm.

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