The implementation in-house dose verification for IMRT and VMAT on breast cancer and NPC cases

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Abstract. IMRT and VMAT have been widely implemented on breast cancer and NPC cases. Dose verification was conducted to ensure the comparison between dose delivered and prescribe dose in TPS to obtain optimal results and the dose delivered. The gafchromic films measurement was done for breast and NPC simulation on RANDO Phantom, irradiating film by 6 MV photon with 200 cGy and scanned with EPSON V700 using 72 dpi. Dose distribution was calculated using the MATLAB-based in-house algorithm. In order to evaluate the gamma index, gafchromic films and MatriXX 2D array were placed in the Multi Cube and irradiated with EPID in same position. Dose distribution differences for IMRT and VMAT with modalities to TPS on film was 5.34% and 6.68% for NPC PTV70; 12.81% and 6.15% for NPC PTV50; 11.14% and 10.80% for breast cancer. Gamma index differences on IMRT with modalities to MatriXX 2D array and EPID was -0.09% and 5.13% for NPC; 0.51% and 2.28% for breast cancer. On the other hand, gamma index difference on VMAT was -1.65% and 1.43% for NPC; 0.19% and 4.38% for breast cancer. This measurement method can be used to verify dose for breast cancer and NPC cases in IMRT and VMAT.

1. Introduction
Radiotherapy is the primary technique for breast cancer and nasopharyngeal carcinoma (NPC) treatment and it could be combined with surgery on breast cancer and chemotherapy on NPC. In NPC planning, there were three CTVs defined, CTV70 for giving a high dose, a CTV60 for reflecting the high risk of local spread in and adjacent to the nasopharynx, and CTV50 for handling nodes around the target. However, the bolus is commonly used in the breast cancer treatment to increase the thickness of the target volume and the usage of high energy photons should be avoided to reduce skin dose [1].

Intensity modulated radiation therapy (IMRT) and volumetric modulated arc therapy (VMAT) are modern techniques in radiotherapy that not only could deliver a high dose to the tumor target precisely but also protected organs and normal tissues nearby the target volume [2]. Dose verification is a series of test to give evidence that the given exposure parameters consistent with the approved plan. Verification on IMRT and VMAT could be performed prior to the treatment (pre-treatment measurements) which are divided into fluence verification and dose verification. Verification is normally done by comparing the dose calculation in irradiated phantom to Treatment Planning System (TPS) [3]. There are two ways of verification, qualitatively and quantitatively. Isodose distribution
was the common qualitative evaluation method and gamma index was a quantitative one. Gamma index is a merger of dose difference (DD) and dose to agreement (DTA) in dose comparison. It was using two completion of criteria, usually 3 mm for spatial tolerances and 3% for dose differences [4]. The gamma index concept has been widely used to compare two dose distribution on cancer radiotherapy. The original gamma index of Low et al. [4] has been improved for better accuracy and efficiency [5].

In this study, dose distribution verification was done on breast cancer and NPC cases with IMRT and VMAT techniques using gafchromic EBT2 films, TLDs, MatriXX 2D array detector, and EPID. Licensed price of radiotherapy dose verification software for film dosimeter has an expensive price, GUI-MATLAB in-house algorithm intent on optimized the calculation of absorbed dose on gafchromic film and minimized dose verification fee.

2. Method

This work was done at Siloam Hospital TB Simatupang using Linac Varian Trilogy which produce high energy photon beams 6 MV and 15 MV. The methodology was divided into treatment planning system, irradiated RANDO phantom, and Multi Cube, and then measured dose distribution using MATLAB, FilmQA Pro, and ImageJ programs. In this study, the measurement was done using Gafchormic EBT2 films (ISP Technologies), EPID, and MatriXX 2D array (IBA Dosimetry) and TLDs as a comparison detector.

2.1. Treatment planning system

Head and chest of RANDO phantom were scanned with computed tomography (CT) simulator with 3 mm slice thickness to get the images. Additional RANDO breast and chest wall were used for breast cancer case. These images were imported to Eclipse ver.10.0. Planning Target Volume (PTV) was created according to clinical experience of target volume contouring in our hospital. The organ at risks (OARs) delineated included spinal cord, brainstem, optic nerves, eyes, and parotid glands for NPC case[6], while spinal cord, lungs, and heart for breast cancer. The IMRT plan in NPC case was generated with nine irradiation fields with equal-spaced gantry angles of 30°. The irradiation fields in breast cancer were consist of seven fields with half rotation from 305° to 125°. The VMAT double arc plans were same with both of The IMRT plans. The irradiation planning was given 70 Gy at NPC and 50 Gy at breast cancer for total treatment or 200 cGy per fraction [7].

2.2. Calibration

For dose assessment, the gafchromic films and TLDs was calibrated using x-ray 6 MV. The experiment used the slab phantoms with the dimension of 30 cm × 30 cm × 1 cm, Source to Axis Distance (SAD) 100 cm, 5 cm depth, and 10 cm × 10 cm field size. Gafchormic films were cut into 4 cm × 4 cm dimension [8] and irradiated at 14, 35, 69, 104, 139, 173, 208, 242, and 277 cGy. Calibration for TLDs was done using single dose for each TLD at 177 cGy. For the readout of TLDs, a TLD reader model Harshaw 3500 was used with a purified N₂. Readings were taken after 48 hours of irradiation. From TL outputs, the individual calibration factors for TLD were determined in terms of μC/cGy to be used to evaluate absorbed doses from their TL outputs.

2.3. Irradiating RANDO phantom and multi cube

The evaluation of dose distribution for IMRT and VMAT planning has been done with dose measurement at RANDO phantom and Multi Cube. Film gafchromic for dose measurement in NPC case was cut with a dimension of 7 cm × 7 cm, whereas it was cut with a dimension of 1 cm × 1 cm for OARs and 4 mm × 20 mm for in spinal cord area. On the other hand, film gafchromic was used on breast dose assessment with a dimension of 6 cm × 6 cm. it was inserted in between two slices of left RANDO breast phantom. For justification of dose measurement, we also used the TLDs and inserted into the hole of RANDO breast. In order to obtain gamma index analysis, gafchromic films with a size of 20 cm x 25 cm was taken placed in the Multi Cube at 11 cm depth. The film was then irradiated by
using IMRT and VMAT in every case of breast cancer and NPC based on radiotherapy planning for RANDO phantom.

2.4. Dose measurement
Irradiated films were scanned with EPSON V700 with 72 dpi after 24 hours. The dose distribution and gamma index analysis was measured using Matlab in-house algorithm. The algorithm calculated the dose distribution base on red channel calibration curve. Pixel value from the scanned film was converted to dose with interpolation referred to the calibration curve. For justification of dose measurement, we also used the FilmQA Pro, ImageJ programs, and TLDs. Gafchromic films were placed in the same position as MatriXX 2D array and measured with MATLAB in-house algorithm to evaluate the gamma index. Furthermore, we used I’mRT OmniPro and EPID programs to evaluate the gamma index of in-house algorithm MATLAB.

3. Result and discussion
The calibration curve was generated by plotting the pixel value of center irradiated calibration film and delivered dose as shown in figure 1. The dose distribution was measured with in-house algorithm and then cumulative dose histogram of the target volume can be generated after Region of Interest (ROI) was defined as described in figure 2.

![Figure 1. MATLAB in-house calibration curve.](image1)

![Figure 2. Dose distribution on NPC PTV70 case.](image2)

| Target | Irradiated Technique | Dose (cGy) | Dose Difference (%) |
|--------|---------------------|------------|---------------------|
|        |                     | MATLAB     | FilmQA Pro | ImageJ | TPS | TLD | MATLAB and TPS | FilmQA Pro and TPS | ImageJ and TPS | TLD and TPS |
| Breast | IMRT                | 183.05 ± 7.90 | 175.50 ± 9.50 | 185.41 ± 7.53 | 206.00 | 191.47 ± 3.36 | 11.14 | 14.80 | 10.00 | 7.06 |
|        | VMAT                | 185.36 ± 4.86 | 175.00 ± 6.30 | 187.63 ± 5.66 | 207.80 | 202.12 ± 2.23 | 10.80 | 15.78 | 9.71 | 3.36 |
| NPC PTV70 | IMRT            | 193.11 ± 4.99 | 180.40 ± 4.30 | 196.45 ± 5.09 | 204.00 | - | 5.34 | 11.57 | 3.70 | - |
|        | VMAT                | 191.31 ± 7.76 | 176.70 ± 4.50 | 194.42 ± 5.04 | 205.00 | - | 6.68 | 13.80 | 5.16 | - |
| NPC PTV50 | IMRT            | 142.49 ± 4.30 | 135.20 ± 3.00 | 141.82 ± 4.84 | 163.43 | 166.31 ± 2.99 | 12.81 | 17.27 | 13.22 | 1.76 |
|        | VMAT                | 169.84 ± 3.16 | 158.00 ± 7.20 | 149.52 ± 5.26 | 160.00 | 162.56 ± 3.62 | 6.15 | 1.25 | 6.55 | 1.60 |
From table 1, dose distribution measurement was done with IMRT and VMAT techniques on breast cancer, NPC PTV70, and NPC PTV50. Dose measurement on NPC PTV70 cases cannot be done using the TLDs because there is no hole in the RANDO phantom. The average dose difference of in-house algorithm to TPS for all cases was 8.82%. Meanwhile, the dose discrepancy of filmQA Pro, ImageJ, and TLDs to TPS were 12.41%, 8.06%, and 3.45%, respectively. The maximum deviation between the film of in-house algorithm measurement and TLD was found to be 11.05%. Homogeneity in the ROI was affected dose distribution measurement on gafchromic films while the small active region of TLDs was received the appropriate dose of the planning.

Dose differences at OARs around of target volume at NPC for all software to TPS were given in table 2. The average dose difference of in-house algorithm, FilmQA Pro, and ImageJ programs to TPS was 5.98%, 4.27%, and 6.68%, respectively. Tong et al. [9] mentioned that the limitation of the dose at spinal cord was 45 Gy for total treatment or 128.57 cGy per fraction. The average absorbed dose for parotid ideally 74.29 cGy per fraction and for eyes was 17.14 cGy per fraction for 70 Gy total dose treatment with IMRT modalities. Based on these references, the dose distribution of the organs at risk was acceptable.

In order to obtain gamma index value, scanned films were compared to planning in DICOM file format by in-house algorithm program as shown in figure 3. Table 3 listed gamma index values for each tumor target and radiation technique, and gamma index differences of in-house algorithm with modalities to MatriXX 2D array and EPID.

A positive value on gamma index differences indicated that the analysis of gamma index from the gafchromic film was better than MatriXX and EPID. Generally, the difference in gamma index of gafchromic films had positive values compare to MatriXX 2D array and EPID. The gamma index result of table 3 proved that gafchromic films had a good sensitivity and spatial resolution.

### Table 2. Dose differences on OAR in NPC cases.

| Irradiated Technique | OAR      | MATLAB Dose (cGy) | FilmQA Pro Dose (cGy) | ImageJ Dose (cGy) | TPS Dose (cGy) | MATLAB TPS Dose Difference (%) | FilmQA Pro TPS Dose Difference (%) | ImageJ TPS Dose Difference (%) |
|----------------------|----------|-------------------|-----------------------|------------------|---------------|-------------------------------|----------------------------------|-------------------------------|
| IMRT                 | Eye      | 3.06 ± 2.23       | 3.10 ± 2.30           | 3.18 ± 0.38      | 2.98          | 2.62                          | 4.03                             | 6.71                          |
|                      | R.P<sup>a</sup> | 45.27 ± 11.48  | 45.80 ± 8.20          | 48.74 ± 7.35     | 45.09         | 0.40                          | 1.57                             | 8.09                          |
|                      | L.P<sup>b</sup> | 48.16 ± 1.87   | 43.30 ± 2.40          | 45.98 ± 1.99     | 44.20         | 8.96                          | 2.04                             | 4.03                          |
|                      | SC<sup>c</sup> | 80.10 ± 6.73    | 85.20 ± 3.40          | 83.42 ± 5.41     | 82.46         | 2.86                          | 3.32                             | 1.16                          |
| VMAT                 | Eye      | 2.75 ± 1.30       | 3.20 ± 1.00           | 2.61 ± 0.51      | 3.02          | 8.94                          | 5.96                             | 13.58                         |
|                      | R.P<sup>a</sup> | 45.39 ± 1.55   | 44.20 ± 4.70          | 44.13 ± 1.47     | 48.57         | 6.55                          | 9.00                             | 9.14                          |
|                      | L.P<sup>b</sup> | 52.91 ± 6.87   | 50.80 ± 9.70          | 48.13 ± 18.25    | 47.40         | 11.62                         | 7.17                             | 1.54                          |
|                      | SC<sup>c</sup> | 97.33 ± 10.79   | 102.30 ± 11.10        | 93.94 ± 10.27    | 103.42        | 5.89                          | 1.08                             | 9.17                          |

<sup>a</sup> R.P = Right Parotid.  
<sup>b</sup> L.P = Left Parotid.  
<sup>c</sup> SC = Spinal Cord.

### Table 3. Gamma index evaluation.

| Target  | Irradiated Technique | Gamma Index (%) | Gamma Index Difference (%) |
|---------|----------------------|-----------------|----------------------------|
| NPC     | IMRT                 | Film<sup>a</sup> | MatriXX<sup>b</sup>       | EPID                | Film and MatriXX | Film and EPID             |
|         | 98.15                | 98.24           | 99.80                      | -0.09               | -1.65              |                             |
|         | VMAT                 | 99.85           | 94.72                      | 98.40               | 5.13               | 1.45                        |
| Breast  | IMRT                 | 99.99           | 99.48                      | 99.80               | 0.51               | 0.19                        |
|         | VMAT                 | 99.58           | 97.30                      | 95.20               | 2.28               | 4.38                        |

<sup>a</sup> Film was calculated using MATLAB in-house algorithm.  
<sup>b</sup> MatriXX 2D array was calculated using IMRT OmniPro program.
4. Conclusion
This study presents a method in which a gafchromic EBT2 film, TLD, ionization chamber, and EPID detectors were employed to evaluate the dose distribution of LINAC IMRT and VMAT techniques on breast cancer and NPC cases. The MATLAB-based in-house algorithm was implemented for dose verification with differences to TPS of 11.14% and 10.80% for breast cancer; 5.34% and 6.68% for NPC PTV70; 12.81% and 6.15% for NPC PTV70. Gafchromic films can be successfully used for gamma index evaluation with the in-house algorithm. Gamma index differences had a maximum value at 5.13% with modalities to MatriXX and 4.38% for EPID. This measurement method can be used to verify dose for breast cancer and NPC cases in IMRT and VMAT while the constructed GUI assists the researcher in performing the measurement with ease.

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