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Homogeneous and inhomogeneous material effect in gamma index evaluation of IMRT technique based on fan beam and Cone Beam CT patient images

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Abstract: Patient-specific Quality Assurance (QA) technique in lung case Intensity-Modulated Radiation Therapy (IMRT) is traditionally limited to homogeneous material, although the fact that the planning is carried out with inhomogeneous material present. Moreover, the chest area has many of inhomogeneous material, such as lung, soft tissue, and bone, which inhomogeneous material requires special attention to avoid inaccuracies in dose calculation in the Treatment Planning System (TPS). Recent preliminary studies shown that the role of Cone Beam CT (CBCT) can be used not only to position the patient at the time prior to irradiation but also to serve as planning modality. Our study presented the influence of a homogeneous and inhomogeneous materials using Fan Beam CT and Cone Beam CT modalities in IMRT technique on the Gamma Index (GI) value. We used a variation of the segment and Calculation Grid Resolution (CGR). The results showed the deviation of averaged GI value to be between CGR 0.2 cm and 0.4 cm with homogeneous material ranging from -0.44% to 1.46%. For inhomogeneous material, the value was range from -1.74% to 0.98%. In performing patient-specific IMRT QA techniques for lung cancer, homogeneous material can be implemented in evaluating the gamma index.

1. Introduction

Modern Linear Accelerator (LINAC) is typically equipped with Multi-Leaf Collimator (MLC), which shapes the beam to conform the target. The conformal radiotherapy will increase the target dose and reduce the dose to surrounding normal tissues [1]. In planning techniques using MLC, an error can occur if either (a) calculated leaf sequences not generated accurately on the fluence used by TPS for dose calculation; (b) information from treatment planning system is not transferred perfectly to the accelerator; or (c) radiotherapy accelerator is not functioning correctly, both mechanically and dosimetrically [2]. Unlike conventional radiotherapy, IMRT uses a number of sub-fields to modulate the intensity of the field on the target. This difference is to deliver high conformity radiotherapy to the target with a gradient of high doses to organs at risk [3].

In addition to the number of sub-fields in IMRT technique, determination of the Calculation Grid Resolution (CGR) in the dose calculation in the TPS also determines the accuracy of the dose calculation [4-5]. Therefore, it is necessary to revisit the problem on discretizing the impact of dose distributions due to a sub-field. In addition, dose accuracy is also required in terms of dose fluence in such planning, being evaluated using a program analysis based on the Gamma Index with criteria % dose difference - DD (difference doses) and distance to agreement (DTA) [6].

The traditional method of quality assurance of IMRT techniques in determining the value of Gamma Index (GI), may yield only limited information about the accuracy of dose distributions of actual patients, since it only accommodates homogeneous material and does not incorporate the effect of the

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presence of the inhomogeneous material, i.e. air spaces, bone structure and soft tissue [7]. Moreover, for radiotherapy on lung cancer, Kappas et. al described that inhomogeneous material with high range of density difference did present in the volume of interest. The study presented the presence of the inhomogeneous material, such as the lungs, would correct the dose at the water for more than 30%, implying the need of taking inhomogeneous material into consideration for dose calculation [8].

The commercial phantom for the quality assurance verification for IMRT setup verification employs a phantom with homogeneous materials, particularly phantoms with 2D-array capabilities during whose usage the direction of gantry is only on one direction, i.e. perpendicular with field detector. Although GI measurements tool which runs by 3-dimensional concept have been commercially available [9-10], the development of these dosimeters in general is still limited in homogeneous material when a beam passes through the phantom dosimeter [11]. This, due to the presence of the inhomogeneous material, may decrease GI value and accuracy of TPS dose calculations for inhomogeneity, with respect to the dose calculation algorithm [12-13].

In general, CBCT imaging with flat panel detector is primarily used for planning verification but Sriram [14] proposed CBCT to be used for replanning and dosimetric verification. The result of that the percentage dose difference based on between Fan Beam CT (FBCT) and kV-CBCT did not exceed 5%. On the other hand, the calibration of CT numbers has been performed using CBCT for the pelvic region planning also does not exceed 5% [15].

The pelvic region is homogenous area compared to the chest area which represented inhomogeneous material.The importance of the accuracy of dosing in IMRT technique in terms of dose distributions, as well as the location and the material. We carried out a study on the effect of homogeneous and inhomogeneous material on evaluation of Gamma Index in IMRT techniques (Intensity Modulated Radiotherapy) based on the image of the patient's Fan Beam and Cone Beam CT.

2. Materials and methods

2.1. Materials

The study was performed at Radiotherapy Department, RSUPN Cipto Mangunkusumo, Jakarta. This study was performed with LINAC Elekta Synergy S which equipped with 6 MV photon energy and CBCT, slab phantom (RW3), homogeneous phantom as in Figure 1(a), inhomogeneous phantom as in Figure 1(b) used cork, acrylic, and resin; cork is equivalent with lungs density and acrylic or resin is equivalent to bone density. All of this material were manufactured from Bayer Materialscience Indonesia Factory. This experiment, we employed PTW 2D Array as detector. Matrixscan and Verisoft software was used to measure the planar dose and evaluate of gamma index, with Philips Pinnacle Planning System as planning software. Images acquired with FBCT modality have been acquired using GE Brightspeed, and images acquired using CBCT modality were acquired using XVI system (integrated with the LINAC).

2.2. Planning system

This work used FBCT- and CBCT-acquired images as illustrated in Figure 2, for five male patients of 30-60 years old with right lungs cancer. Parameter for FBCT were used Chest protocol institution (kV 120; mA 10; and 2.5 mm slice thickness) and CBCT used Medium FOV (kV 120; mA 25, and ms 40). The data acquired from those modalities, planning was generated with IMRT technique. CBCT image from XVI was transferred to TPS by combining the target and OAR FBCT delineation. FBCT and CBCT re-planning was carried out using two of CT number calibration curves. CT number calibration curves are from FBCT and CBCT from a previous study [20], IMRT technique re-planning was performed by using seven coplanar fields [16]. This study used Philips Pinnacle Planning System with 0.2 cm and 0.4 cm calculation grid resolutions (CGR) and used 30, 50, and 70 segments for each planning. The CGR variation was used to observe its impact on dose distribution, especially in 0.4 cm [9] because the recommendation of maximum CGR for lungs cancer is 0.3 cm [4].

2.3. Phantom setup for measurements

The homogeneous and inhomogeneous materials phantoms were scanned using FBCT and CBCT. The setup for homogeneous slab phantom consist of (RW3, ρ=1.045 gr/cc) [17] from PTW with various depth of the detector which were ; 1.5 cm, 5 cm, 10 cm with 5 cm for back scatter. The inhomogeneous material simulated the chest area which was arranged as :

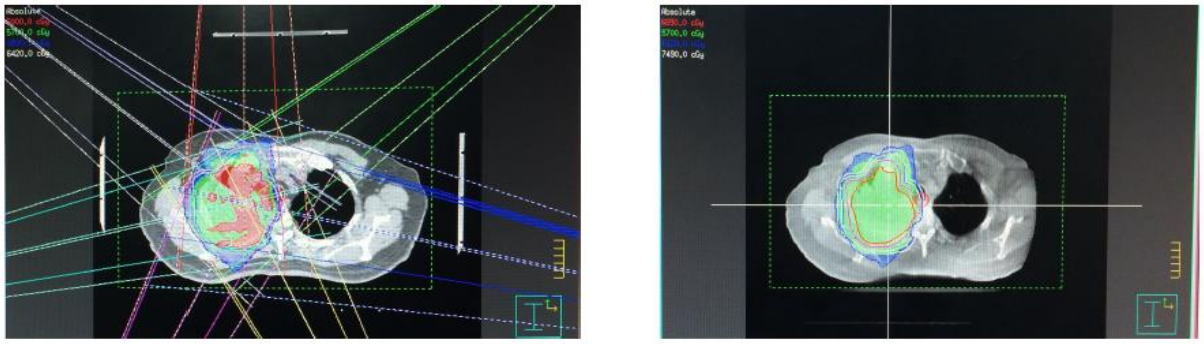
- Slab phantom with 3 cm thickness for upper and lower position [18].
- Resin material with 1 cm thickness (ρ=1.363 gr/cc) [19] and 0.4 cm thickness of acrylic (ρ=1.060 gr/cc) [20] as bone simulation set for upper and lower position.
- Cork material with 15 cm thickness (ρ=0.210 gr/cc) [20] as lung tissues simulation. The lungs and bones thickness was obtained from measurement data with FBCT modality for lung cancer patient in Radiotherapy RSCM in 2012 until March 2015. The PTW 2D Array detector was set in 1.5 cm, 5 cm, and 10 cm thickness of lung tissue.

The image of phantom was transferred to Philips Pinnacle Planning System to generate planar dose calculation. The isocenter was on 100 cm SAD with effective point of detector (0.5 cm from the surface of the PTW 2D Array detector) and on the center of the detector. All gantry directions were modified into 0° angle on every planning and modality, so that its planar dose might be obtained.



(a) (b)

Figure 1. Set up Phantom with : (a) Homogeneous and (b) Inhomogeneous phantom



(a) (b)

Figure 2. IMRT Treatment Planning with: (a) FBCT- and (b) CBCT-acquired images

2.4. Gamma index evaluation

The setup on the measurement corresponded with the setup on the planning. Planar dose from measurement was compared with planar dose from TPS for all planning with DTA and DD criteria 2 mm/2% and 90% for the passing rate [21, 9, 22].

3. Results

3.1. Gamma index evaluation of calculation grid resolution

3.1.1. Homogeneous material FBCT modality Table 1(a) shows a deviation of GI value between the Calculation Grid Resolution (CGR) of 0.2 and 0.4 cm in images of homogeneous material acquired with FBCT modality. A CGR of 0.2 cm is used as a reference. The greatest deviation of GI value for IMRT of 70 segments at a depth of 1.5 cm has a positive sign (+), meaning that CGR of 0.4 cm is higher than 0.2 cm. The deviation with a negative sign (-) has a meaning that CGR of 0.2 cm is higher than 0.4 cm. In deviation sign (-) as seen in Table 1(a), 50 segments at a depth of 1.5 cm is the greatest. Deviation value (from a negative value to a positive value) is increase along with the addition of depth for 50 segments. Different phenomena are shown in Table 1(a) for 70 segments, where deviation decreases with increasing of depth. Table 1(a) shows deviation is 0% at a depth of 5 cm, which indicates the value of CGR 0.2 cm is identical to CGR 0.4 cm. At the depth of 10 cm, all variations of segment have positive sign (+). At a depth of 10 cm, the deviation decreases with the increase of the number of segments with the greatest deviation value in 30 segments is 0.47% and the least value in 70 segments is 0.04%.

3.1.2 Homogeneous material CBCT modality Table 1(b) shown a deviation of GI value between the CGR of 0.2 and 0.4 cm in images of homogeneous material acquired using CBCT modality. As seen in Table 1(b) at the overall depth and technique, the deviation is negative (-), meaning that the average value of GI on CGR 0.4 cm was lower than the average value of GI on CGR 0.2 cm. the greatest deviation in 30 segments at a depth of 5 cm with a value of -1.13% and the least deviation in 50 segments at the same depth with a value of -0.04% was described in Table 1(b). the least deviation is in 30 segments with a value of -0.44% and -0.29% at 1.5 cm and 10 cm depths . In both depths, the greatest deviation value was found at the same technique (see Table 1(b)) i.e in 50 segments with a value of -1.00% for a depth of 1.5 cm and – 1.10% for a depth of 10 cm. For a depth of 5 cm, the least deviation value of -0.04% on the 50 segment and the greatest deviation value of -1.13% for 30 segments.

3.1.3. Inhomogeneous material FBCT modality Table 2(a) shows a deviation with the same parameters as Table 1(b) but using images of inhomogeneous material acquired with FBCT modality. Table 2(a) shows overall deviation denoting that average value of GI on CGR 0.4 cm being lower than CGR 0.2 cm. The greatest deviation (Table 2(a)) at a depth of 5 cm IMRT technique 30 segments is -2.54% and the least deviation of GI value at 50 segment is -0.04% at a depth of 10 cm. When compared to all three variations of depth to the entire segment, the least deviation value is at a depth of 1.5 cm and the greatest deviation of GI value is at a depth of 5 cm.

For a depth of 1.5 cm, Table 2(a) shown that the deviationof GI value increases along with the increase of number of segments, with the least value at this depth being -0.11% and the greatest value was being -0.55%. Meanwhile at a depth of 5 cm, the deviation of GI value inversely proportional to the depth of 1.5 cm. With the trend at a depth of 5 cm, a deviation decreases with increasing the number of segments (see Table 2(a)). The highest and lowest deviation of GI value at this depth were - 2.54% and -1.42%. At a depth of 10 cm, as seen in Table 2(a), the least deviation of GI value was found at 50 segments, with a value of -0.04% and the greatest deviation value was 0.47%, found on 30 segments.

3.1.4. Inhomogeneous material CBCT modality For CBCT-acquired inhomogeneous material, a deviation of GI value between CGR is 0.2 cm and 0.4 cm as seen in Table 2(b). Almost all deviation values were negative, except at a depth of 5 cm segments 50 (close to 0%), and depth of 10 cm which was 0.98%. Table 1(b) also shown the greatest deviation of GI values in the sign (-) at a depth of 1.5 cm segment 70 with a value of -1.74% and the greatest deviation in sign (+) at a depth of 10 cm 50 segments with a value of 0.98%. For 50 segments, it was seen that deviation was increasingly moving towards (+) with increasing depth. Furthermore in Table 2(a), the greatest deviation value for a depth of 1.5 cm, 5 cm and 10 cm were at 70 segments with a deviation value - 1.74%, -0.99%, and -1.24%, respectively, and the least being in 50 segments for the three depths, with the value being -0.40%, 0.01%, 0.98%, at the depth of 1.5, 5, and 10 cm, respectively.

Technique	Deviation (%)		
	Depth		
	1.5 cm	5 cm	10 cm
30 Seg	0,66	0,00	0,47
50 Seg	-0,29	0,00	0,43
70 Seg	1,46	0,00	0,04

(a)

Technique	Deviation (%)		
	Depth		
	1.5 cm	5 cm	10 cm
30 Seg	-0,44	-1,13	-0,29
50 Seg	-1,00	-0,04	-1,10
70 Seg	-0,77	-0,30	-0,66

(b)

Figure 3. Deviation of average GI value between CGR 0.2 cm and 0.4 cm in homogeneous materials: (a) FBCT Modality and (b) CBCT Modality

Technique	Deviation (%)		
	Depth		
	1.5 cm	5 cm	10 cm
30 Seg	-0.11	-2.54	0,47
50 Seg	-0,26	-1,70	-0,04
70 Seg	-0,55	-1,42	-0,29

(a)

Technique	Deviation (%)		
	Depth		
	1.5 cm	5 cm	10 cm
30 Seg	-0,79	-0,38	-1,07
50 Seg	-0,40	0,01	0,98
70 Seg	-1,74	-0,99	-1,24

(b)

Figure 4. Deviation of average GI value between CGR 0.2 cm and 0.4 cm in inhomogeneous materials: (a) FBCT Modality and (b) CBCT modality

4. Discussion

In general, the use of CGR in the evaluation of GI resulting in GI values being more varied in CGR 0.4 cm in comparison to those of 0.2 cm. This might be due to reduced accuracy in the calculation of the dose with the use of CGR being greater than 0.2 cm. Generally, the deviation of GI value using CGR 0.2 cm and 0.4 cm at 1.5 cm depth increased along with increasing number of segment, except for the inhomogeneous phantom for CBCT modality. However, there were no trend with number of segment at 5 and 10 cm depths. Similarly, there was no trend for the effect of GI at same number of segment with different depth between CGR 0.2 cm and 0.4 cm. However, the use of CGR 0.4 cm still suffice for use on the purpose of therapeutic planning. Additionally, added presence of irregularities, thickness, and volume may present more inaccuracy in terms of dose calculations using CGR 0.4 cm in comparison with the same situation using CGR 0.2 cm [23, 24, 4, 5, 25, 13]. This study, however, had not observed a significant difference in both existing CGR.

5. Conclusion

Patient-specific IMRT QA techniques for lung cancer can be implemented using homogeneous material in evaluating the gamma index and optimum depth at 5 cm using CGR 0.2 cm.

6. References

[1] Jen-Sai T & Wazer D E 1998 Dosimetric Verification of the Dynamic Intensity-Modulated Radiation Therapy of 92 Patients *Int. J. Radiation Oncology Biol. Phys.* **40**(5) 1213–1230

[2] Van Zijtveld M. et al. 2006 Dosimetric Pre-treatment Verification of IMRT using an EPID; Clinical Experience *Radiotherapy and Oncology* **81**(2) 168–175

[3] DeLuca P M & Seltzer S M 2008 *Journal of the ICRU: ICRU Report 83 Prescribing, Recording, and, Reporting Photon-Beam Intensity-Modulated Radiation Theraphy (IMRT)*
[4] Benedict S H et al. 2010 Stereotactic Body Radiation Therapy: The Report of AAPM Task Group 101 *Medical Physics* **37**(8) 4078–4101
[5] Li J S et al. 2010 Uncertainties in IMRT Dosimetry *Medical physics* **37** 2491–2500
[6] Donmez Kesen N & N N 2014 Pre-Treatment Dose Verification of IMRT Using Gafchromic EBT3 Film and 2DArray *Journal of Nuclear Medicine & Radiation Therapy* **05**(02) 3–8
[7] Chung K et al. 2013 Radiochromic Film Based Transit Dosimetry for Verification of Dose Delivery with Intensity Modulated Radiotherapy *Medical physics* **40**(2) 021725
[8] Kappas C & Rosenwald J -C. 1995 Quality Control of Inhomogeneity Correction Algorithms in Treatment Planning System. *Science*, **32**(3) 847–858
[9] Van Esch A, Basta K & Evrard M 2014 The Octavius1500 2D Ion Chamber Array and its Associated Phantoms: Dosimetric Characterization of a New Prototype *Medical physics* **41**(9) 091708
[10] Oldham M et al. 2008 An investigation of the Accuracy of an IMRT Dose Distribution Using Two-and Three-Dimensional Dosimetry Techniques *Medical physics* **35**(5) 2072–2080
[11] Low D A et al. 2011 Dosimetry Tools and Techniques for IMRT *Medical physics* **38**(3) 1313–1338
[12] Lye J et al. 2014 A 2D Ion Chamber Array Audit of Wedged and Asymmetric Fields in an Inhomogeneous Lung Phantom *Medical physics* **41**(10) 101712–1 –101712–11
[13] Rock L et al. 2004 *Tissue Inhomogeneity Corrections for Megavoltage Photon Beams*
[14] Sriram P 2011 A Study on Evaluation of kV-CBCT-Image-Based Treatment Planning Using Anthropormorphic Phantom *Journal of Medical and Biological Engineering* **31**(6) 429
[15] Kustriyadi H 2013 *Perbandingan Distribusi dosis Radioterapi antara Citra Volumetrik kV-Cone Beam dengan Fan Beam CT* Universtias Indonesia
[16] Kartutik et al. 2016 Comparison of Radiotherapy Dosimetry for 3D-CRT, IMRT, and SBRT Based on Electron Density Calibration. *Journal of Physics: Conference Series 694 (2016) 012017*
[17] Hill R F, Brown S & Baldock C, 2008 Evaluation of the Water Equivalence of Solid Phantoms Using Gamma Ray Transmission Measurements. *Radiation Measurements* **43**(7) 1258–1264
[18] Mckenzie E M et al. 2014 Toward Optimizing Patient---Specific IMRT QA Techniques in the Accurate Detection of Dosimetrically Acceptable and Unacceptable Patient Plans *Medical physics* **41** 121702–1 –121702– 15
[19] Heilemann G, Poppe B & Laub W 2013 On the Sensitivity of Common Gamma-Indeks Evaluation Methods to MLC Misalignments in Rapidarc Quality Assurance *Medical Physics*, 40(3), p.031702.
[20] Park J. et al. 2014. Optimal set of Grid Size and Angular Increment for Practical Dose Calculation Using the Dynamic Conformal Arc Technique: a Systematic Evaluation of the Dosimetric Effects in Lung stereotactic body radiation therapy *Radiation Oncology* **9**(5) 1–12
[21] ESTRO 2013 Oncology & Radiotherapy *Radiotherapy and oncology: journal of the European Society for Therapeutic Radiology and Oncology* **115**(9)
[22] Hsu S -H Et al. 2010 Dose Discrepancies in the Buildup Region and Their Impact on Dose Calculation for IMRT fields *Medical physics* **37**(5) 2043–53

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