

Dosimetric evaluation of IMRT plan for homogenous and inhomogeneous medium using AAPM TG-119 protocol

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Abstract. The American Association of Physicists in Medicine (AAPM) TG-119 protocol has been applied for dose verification in IMRT technique. However, some criteria in the protocol need to be verified for inhomogeneous medium and small volume targets. Hence, the purpose of this study was to verify the assessment criteria of dose verification in AAPM TG-119 for inhomogeneous medium and small volume targets. The work has been conducted by dose verification for homogeneous (phantom A) and inhomogeneous phantoms (phantom B and C) on two geometrical targets: C-shape and circular targets. The targets were simulated using 7 static dMLC IMRT fields at two different depths of 5 g/cm² and 10 g/cm². The dose optimisation and calculation were done by using Pinnacle³ for 6 MV photons beam. The planning objectives were set according to AAPM TG-119 parameters. The plan analysis was conducted by Conformity Index and Homogeneity Index. The point dose measurements were conducted with Exradin A16, Semiflex 0.125cc, and Gafchromic EBT3. The plan results show that CI for C-shape target is in the range of 0.710-0.999 at 10 g/cm² depth and 0.691-1.613 at 5 g/cm². In addition, HI for C-shape and circular were in the range of 6.3%-58.7% and 5.4%-87.1% for 10 g/cm² depth. The measurement results show that the dose measurement at inhomogeneous medium and small volume targets are much lower than the criteria in AAPM TG-119. In conclusion, the criteria in the AAPM TG-119 cannot be fully implemented for inhomogeneous medium and small volume targets.

1. Introduction

Modern radiotherapy techniques have been widely used as promising and more effective cancer treatment. These techniques, such as Intensity Modulated Radiation Therapy (IMRT), Image-Guided Radiation Therapy (IGRT), Stereotactic Body Radiation Therapy (SBRT) and Stereotactic Radiosurgery (SRS), have been developed and applied to achieve optimum doses to the target and spare healthy tissue around the targets [1][2]. Within those techniques, IMRT was the most been used for various diseases. In 2009, the AAPM has published Task Group 119 for verification protocol in IMRT which contains some geometric tests, such as multitargets, mock prostate, mock head and neck, and C-shape target. This TG-119 has suggested performing all the tests on point dose measurement, planar dose measurement, and planar dose field by field measurement [3]. The AAPM TG-119 protocol has been applied for dose verification in IMRT technique.

The procedures of dose verification in AAPM TG-119 have been carried out in a solid water phantom (PMMA), which is a homogeneous medium. In fact, human body consists of materials having different densities such as lungs, soft tissues and bones which may represent inhomogeneity condition. Hence, the procedures of dose verification in the protocol might not fully represent the dose verification for human body (patients) and might cause a dose perturbation due to the inhomogeneity issues [4]. Moreover, the dose perturbation due to inhomogeneity issues might be more complex due to the use of small field technique for treating small volume targets. The combination of the inhomogeneity problem



and small volume target might cause a significant dose perturbation. The dose perturbation might be caused by some issues such as the lack of electronic equilibrium; this condition might occur because the field size is too small so that the energy which enters and leaves the volume target is not in the equilibrium state. Other issues are steep dose gradient, source occlusion and volume averaging effect, which occur when the range of the secondary electrons is too large compared to the chamber size, so that more electron will scatter laterally out of the field [1][5][6][7]. However, some criteria in the protocol need to be verified for inhomogeneous medium and small volume targets. For those reasons, this study has been done to verify the assessment criteria of dose verification in AAPM TG-119 for inhomogeneous medium and small volume targets.

2. Methodology

2.1. Plan Optimisation

This study has used the CT images which have been generated by GE Brightspeed CT simulator and Pinnacle3® treatment planning system (TPS) (Philips Radiation Oncology Systems, Fitchburg, WI) with an adaptive convolution algorithm. The dose measurement was performed using 6 MV photon beam-Synergy-S (Elekta AB, Stockholm, Sweden) accelerator. The measurement used homogeneous solid water (phantom A), inhomogeneous phantom that consist of lung, tissue, and bone (compact and spongy bone) equivalent materials with mass target that consists of tumour equivalent materials as the target in the lung (phantom B) and inhomogeneous phantom without mass target equivalent (phantom C). The inhomogeneous phantoms (phantoms B and C) were set by sandwich model. The plan and measurements also used C-shape and circular targets which have been adopted from AAPM TG-119 protocol. The treatment planning was generated by using IMRT technique with invers plan optimisation using seven gantry angles (14°, 34°, 138°, 180°, 229°, 327°, and 349°) and avoiding the lateral side of the phantoms using 200 cGy prescribed dose.

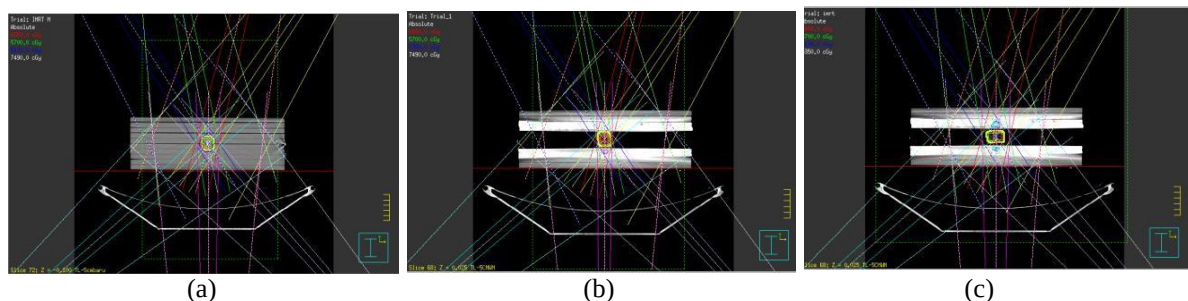


Figure 1. TPS plan for three type of phantom: **(a)** Homogeneous phantom (Phantom A); **(b)** Inhomogeneous phantom with tumour equivalent material (Phantom B); **(c)** Inhomogeneous phantom without tumour equivalent material (Phantom C).

2.2. Point Dose Verification

Point dose measurement was conducted using ionization chamber Exradin A16, Semiflex 0.125cc, and Gafchromic EBT3 in the isocentre, in 3 types of phantoms. The Semiflex, was only used in phantom A and phantom C since its size could not fit in the middle of mass target (phantom B). C-shape target and circular target volumes are 9 cm³ and 8 cm³ respectively with 0.2 cm PTV margins.

2.3. Analysis of the Results

The analysis was conducted based on the parameters of AAPM TG-119 such as Conformity Index (CI), Homogeneity Index (HI), dose goals, and measurement analysis based on the discrepancies between planning and measurement. Conformity index analysis was performed involving the ratio of volume that cover 95% dose ($V_{95\%}$) and volume of PTV (V_{PTV})[8][9] using equation (1)

$$CI = \frac{V_{95\%}}{V_{PTV}} \quad (1)$$

Homogeneity index (equation (2)) analysis involves the ratio of the dose that covers 2% volume ($D_{2\%}$), dose covers 98% volume ($D_{98\%}$), and the dose cover 50% volume ($D_{50\%}$) of PTV. An HI of zero indicates that the absorbed-dose distribution is almost homogeneous[10].

$$HI = \frac{D_{2\%} - D_{98\%}}{D_{50\%}} \quad (2)$$

The measurement discrepancies follow equation (3)

$$discrepancy = \frac{D_{measured} - D_{plan}}{D_{prescription}} \quad (3)$$

The agreement criterion was determined according to International Commission on Radiation Unit and Measurements (ICRU) recommendation, which suggests the accuracy of $\pm 5\%$ in the delivery of an absorbed dose to a target volume [11].

3. Results and discussions

3.1. Conformity Index, Homogeneity Index, and dose goals

The results of the CI and the HI in the small field IMRT technique are shown in Table 1 and 2. We know that IMRT technique can produce a good agreement in CI and HI [12]. In this research, the result of CI in phantom A has shown that it is in agreement with previous study Nainggolan[13] and Mynapati[14]. In contrast, the result in phantoms B and C has indicated slightly different CI and HI. This condition is caused by the inhomogeneity of the phantom material and significantly affected by the use of small field technique. For homogeneity index (HI), phantoms B and C have shown the higher value of HI while phantom A gives a lower value of HI, but it does not mean better from the previous study[13][14] since the implementation of small field technique in phantom A.

The result of treatment planning system plan (TPS plan) in 10 g/cm² and 5 g/cm² depth has shown the same patterns for phantoms B and C, which have high value for HI and a low value for CI. Consequently, inhomogeneity of the material and field size have affected the value of generated CI and HI, especially for the circular and C-shape targets. The patterns of CI and HI in the phantoms have been affected by the type of phantom materials and depth of the target position.

Table 3 until Table 5 have shown the result of the dose goals between the phantom plan and the criteria in AAPM TG-119. The results were analyzed for the value of D_{95} , D_{10} for the target C-shape PTV, while the value of D_5 were calculated on the core areas in the isocenter.

Table 1. The Comparison of CI and HI in the depth of 10 g/cm² target position

Comparison	Phantom A		Phantom B		Phantom C		IMRT[13]		IMRT[14]	
Geometry	C-shape	Circular	C-shape	Circular	C-shape	Circular	C-shape (hard)	Multi target	C-shape (hard)	Multi target
Homogeneity Index (%)	6.3	5.4	58.7	77.4	57.1	87.1	15.4	4.2	11.02	4.56
Conformity Index	0.999	1.122	0.736	0.450	0.710	0.334	1.355	1.357	1.18	1.23
Amount of fields	7	7	7	7	7	7	9	7	9	7
Dose per fraction	200	200	200	200	200	200	200	200	200	200

Table 2. The Comparison Conformity Index and Homogeneity Index in 5 g/cm² depth

Comparison	Phantom A		Phantom B		Phantom C		IMRT[13]		IMRT[14]	
Geometry	C-shape	Circular	C-shape	Circular	C-shape	Circular	C-shape (hard)	Multi target	C-shape (hard)	Multi target
Homogeneity Index (%)	7.0	5.9	80.4	67.5	63.4	64.6	15.4	4.2	11.02	4.56
Conformity Index	1.613	1.165	0.691	0.847	0.693	0.729	1.355	1.357	1.18	1.23
Amount of fields	7	7	7	7	7	7	9	7	9	7
Dose per fraction	200	200	200	200	200	200	200	200	200	200

Table 3. The Dose goals comparing based on Phantom A plan

	C-shape			Circular (multitarget)	
Structure	PTV	PTV	Core area (hard)	PTV	PTV
parameters	D_{95} (cGy)	D_{10} (cGy)	D_5 (cGy)	D_{99} (cGy)	D_{10} (cGy)
Dose goal (cGy)	5000	<5500	<1000	>5000	<5300
d=5 g/cm²	4858 (-2.8%)	5121 (-6.9%)	5069 (406.8%)	5140 (2.8%)	5723 (8.0%)
d=10 g/cm²	4703 (-5.9%)	6313 (14.8%)	5955 (495.5%)	4801 (-4.0%)	5057 (-4.6%)
AAPM TG-119	5010	5702	1630	4955	5455
IMRT [13]	5057	5596	1558	5023	5286
IMRT[14]	5000	5482	1585	5007	5358

Table 4. The Dose goals comparison based on Phantom B plan

	C-shape			Circular (multitargets)	
structure	PTV	PTV	Core area (hard)	PTV	PTV
parameters	D_{95} (cGy)	D_{10} (cGy)	D_5 (cGy)	D_{99} (cGy)	D_{10} (cGy)
Dose goal (cGy)	5000	<5500	<1000	>5000	<5300
d=5 g/cm²	2504 (-49.9%)	5357 (-2.6%)	5245 (424.5%)	1803 (-63.9%)	5247 (-1.0%)
d=10 g/cm²	4670 (-6.6%)	5589 (1.6%)	5619 (461.9%)	886 (-82.2%)	5132 (-3.2%)
AAPM TG-119	5010	5702	1630	4955	5455
IMRT[13]	5057	5596	1558	5023	5286
IMRT[14]	5000	5482	1585	5007	5358

Table 5. The Dose goals comparing based on Phantom C plan

	C-shape			Circular (multitarget)	
structure	PTV	PTV	Core area (hard)	PTV	PTV
parameters	D_{95} (cGy)	D_{10} (cGy)	D_5 (cGy)	D_{99} (cGy)	D_{10} (cGy)
Dose goal (cGy)	5000	<5500	<1000	>5000	<5300
IMRT, d=5 g/cm²	3115 (-37.7%)	5237 (-4.8%)	5264 (426.4%)	1578 (-68.5%)	5218 (-1.6%)
IMRT, d=10 g/cm²	3383 (-32.3%)	5589 (1.6%)	5619 (461.9%)	1496 (-70.1%)	5244 (-1.1%)
AAPM TG-119	5010	5702	1630	4955	5455
IMRT [13]	5057	5596	1558	5023	5286
IMRT[14]	5000	5482	1585	5007	5358

Remarks :

 D_{95} : Dose which covers 95% of target volume (PTV) D_{10} : Dose which covers 10% of target volume (PTV) D_5 : Dose which covers 5% of core areas (isocentre) D_{99} : Dose which covers 99% of target volume (PTV)

The Table 3 has shown that the dose goal of phantom A is close to the dose goal of TG-119 at about 6% and 15% for D_{95} and D_{10} respectively, but it has a big difference at about 495% compared to the dose goal from TG-119 for core area (D_5). Moreover, the result of analysis on the D_{99} and D_{10} for PTV of circular target has the discrepancy less than 5%. The evaluations of D_{95} , D_{10} and D_5 in phantoms B and C give higher result than the dose goal in AAPM TG 119 up to 461.9%. Conversely, the achieved dose at D_{95} and D_{10} in phantom B is lower than dose goal in AAPM TG 119 at about 49.9% and 37.7%.

3.2. Measurement discrepancies

The discrepancy of the results in this study has been shown in Fig 2. The measurement on the inhomogeneous phantom with mass (phantom C) has presented that the discrepancy reached up to -17.7% by using Exradin A16 and -12.8% by using the Gafchromic EBT3 film.

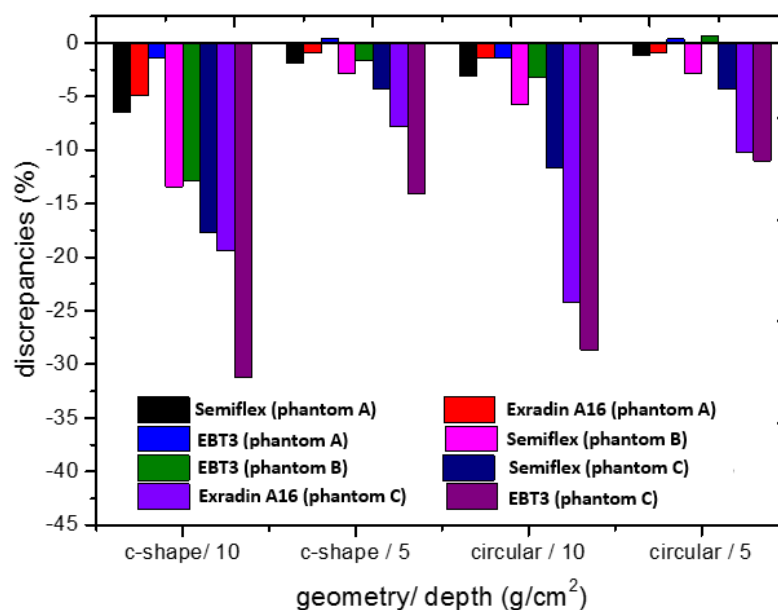


Figure 2. Discrepancies for all phantom measurement

However, the measurements in phantom C, have shown the different patterns that the dose reduction has reached -31.2% in EBT3 measurement. In addition, about the measurement in phantom C, the dose reduction is higher than the measurement in phantom B, because the location of measurement is in the low-density area [4][15]. The phenomena might be caused by the target mass attenuation which might involve in the measurements.

The highest dose reduction for phantom A, has occurred the C-shape target measurement. It has shown that the dose reduction of the Exradin A16 is lower than Semiflex measurement. This condition has occurred due to the smaller sensitive volume of Exradin A16 compared to Semiflex, so that the volume averaging effect can be minimised. On the other hand, EBT3 has produced the lowest dose reduction because of its highspatial resolution[15][16].

4. Conclusion

The result of dose measurement in inhomogeneous medium and small volume targets is much lower than the criteria in AAPM TG-119, and then criteria in the AAPM TG-119 could not be fully implemented for inhomogeneous medium and small volume targets.

5. References

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Acknowledgements

The authors would like to express special thanks to the Department of Radiotherapy RS Cipto Mangunkusumo, also to the Laboratory of Medical Physics, University of Indonesia which provided equipment needed in this research. This study was supported by Hibah PITTA Universitas Indonesia 2016 (contract number 2051/UN2.R12/HKP.05.00/2016)