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Comparison of Gamma Index Passing Rate in Several Treatment Planning System Algorithms

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ABSTRACT

The verification of dose calculation algorithm in a new Treatment Planning System (TPS) can be evaluated by comparing the passing rate of the gamma index analysis of the evaluated algorithm and the clinically implemented algorithms. In the present investigation, the gamma index passing rates was investigated as the reference data in the verification of the new three-dimensional TPS. The algorithms which are used in this study are Pencil Beam Convolution (PBC) version 11.0.31 and Anisotropic Analytical Algorithm (AAA) version 11.0.31 in Eclipse v.11 TPS, and Fast Convolution (FC), Adaptive Convolution (AC), and Collapsed-Cone Convolution (CCC) in Pinnacle^3 v.7.6c TPS. The 6 MV X-ray beam configurations were varied in the depth of measurement points, field sizes, source-to-surface distances, and wedge angles. The dose measurement was done using MatriXX Evolution and PTW 2D-array seven29. Then, OmniPro ImRT and Verisoft 3.1 software were chosen to analyze the gamma index from varied gamma criteria (3 %/3 mm, 2 %/3 mm, 3 %/2 mm, and 2 %/2 mm). Overall, the passing rate of AAA is the highest rate obtained of all algorithms. For gamma criterion of 2 %/2 mm, the passing rate of AAA was 93.18 % ± 7.21 %, the passing rate of PBC was 89.76 % ± 7.21 %, and the passing rate of convolution algorithms was 76.84 % ± 11.10 %.

INTRODUCTION

Radiotherapy is one of the modalities in cancer treatment which used the radiation sources to kill the cancer cells. Prior to delivering the radiation dose, the treatment planning of radiotherapy has to be optimized. The Treatment Planning System (TPS) is used to create the beam shape and dose distribution for maximizing tumor control and minimizing normal tissue complication. Therefore, the accuracy and quality of clinical implementation of the TPS must be determined by commissioning which has been arranged in International Atomic Energy Agency Technical Report Series No. 430 (IAEA TRS-430), Association of Physicists in Medicine Radiation Therapy Committee Task Group 53 (AAPM TG-53), and Association of Physicists in Medicine Medical Physics Practice Guideline 5.a (AAPM MPPG-5.a) [1-3].

Verification of TPS algorithm performance is a part of commissioning processes because the high accuracy in radiotherapy can be reached if TPS algorithms are able to calculate accurately. This performance of TPS algorithm can be evaluated quantitatively using gamma index passing rates. Gamma index analysis is a common technique to evaluate the dose distribution calculation. The analysis compares the measured dose as reference information to the calculated dose by using the patient's planning verification software. The number of measurement points that deal with the criteria is mentioned as the passing rate. This paper investigated the passing rates of several clinical dose calculation algorithms for 6 MV X-ray beam, such as Anisotropic Analytical Algorithm (AAA) and Pencil Beam Convolution (PBC) which are installed in TPS of Eclipse v.11 at MRCCC Siloam Hospitals Semanggi, Fast Convolution (FC), Adaptive Convolution (AC), and Collapsed Cone Convolution (CCC) which are installed in TPS of Pinnacle^3 v.7.6c at Pusat Pertamina Hospital.

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THEORY/CALCULATION

Many parameters can be used to estimate the quality of dose calculation algorithm, such as dose deviation, gamma index passing rate, confidence limit, and action level. The dose deviation (δ) was obtained from Eq. (1) where D_{calc} is calculated dose and D_{meas} is measured dose [4]. It was used for the evaluation of point dose calculation at the central axis.

$$\delta = 100\% \times (D_{calc} - D_{meas}) / D_{meas} \quad (1)$$

Gamma index analysis which combines dose deviation and distance-to-agreement with acceptance criteria, compares the measured dose as reference information to the calculated dose. It can be obtained by using the patient's planning verification software. The number of measurement points that deal with the criteria is mentioned as the passing rate. The gamma index analysis has been applied in many studies [5-7].

Confidence limit (CL) has been used in applying gamma index passing rates [8,9]. It was obtained from Eq. (2) based on AAPM TG-119 where mean is percentage average of the passing rates and σ is standard deviation. This concept is useful for comparison of large numbers of data in comparable test situations because it combines the influence of systematic and random deviations [4].

$$CL = (100 - mean) + 1.96\sigma \quad (2)$$

Crowe et al. has identified action levels that maintain acceptable passing rates and recommended equivalent action levels for many criteria. Action level of 90 % for 3 %/3 mm is equivalent with 85 % for 2 %/3 mm, 83 % for 3 %/2 mm, and 76 % for 2 %/2 mm. The equivalent action levels provide a guide for clinical decision making and comparison of gamma evaluation results from studies using different evaluation criteria [10].

EXPERIMENTAL METHODS

The study compared the passing rates of gamma index analysis of five algorithms. The study was performed in Siloam MRCCC Hospital and Pusat Pertamina Hospital using 6 MV X-ray beams for various depth doses, field sizes, source-to-surface distances (SSDs), and wedge angles as suggested by IAEA TRS-430, AAPM TG-53, and AAPM MPPG-5.a. The specification of the equipment and settings in this study is shown in Table 1. The research methodology is shown in Fig. 1. The simulated treatment planning was performed by each TPS with many parameters as shown in Table 2. Each algorithm in its TPS calculated the same dose of 6 MV energy yet generated different dose distribution and monitor unit (MU). All of the simulated planning was delivered to the phantom and measured with MatriXX Evolution and PTW 2D-array seven29 detectors. The gamma index analysis which was obtained using OmniPro ImRT and Verisoft 3.1 with low dose threshold at 5 % of the maximum dose, isocentrically normalization, and gamma criteria 3 %/3 mm, 3 %/2 mm, 2 %/3 mm, and 2 %/2 mm yielded a passing rate as the evaluated parameter. Besides, the dose at the central point of planar dose measurement was compared to point dose measurement with FC65-G ionization chamber for the same parameters of energy and configuration for 100 MU and 10 cm depth, respectively.

Table 1. The specification of the equipment and settings used in each hospital.

Equipment / settings	MRCCC	RSPP
TPS	Eclipse v.11	Pinnacle3 v.7.6c
Algorithm	PBC, AAA	CCC, AC, FC
Linac	Varian Clinac iX	Siemens Primus
CT Scan	Philips 16-slices	Philips 64-slices
Phantom	Slab	Slab, virtual water
Software	OmniPro ImRT, Verisoft 3.1	Verisoft 3.1
Planar dose resolution	0.059 cm	0.5 cm

Table 2. The parameters used in each treatment planning configuration with 6 MV photon beam at 0˚ gantry angle.

Case	Set Up	Reference Point	Measurement Point	Field Size [cm^2]	Beam Modifier
Depth	SAD 100 cm	10 cm	10 cm	10x10	-
	SAD 100 cm	10 cm	5 cm	10x10	-
	SAD 100 cm	10 cm	1 cm	10x10	-
Field Size	SAD 100 cm	10 cm	10 cm	5x5	-
	SAD 100 cm	10 cm	10 cm	10x10	-
	SAD 100 cm	10 cm	10 cm	15x15	-
	SAD 100 cm	10 cm	10 cm	20x20	-
	SAD 100 cm	10 cm	10 cm	24x24	-
SSD	SSD 80 cm	10 cm	10 cm	10x10	-
	SSD 90 cm	10 cm	10 cm	10x10	-
	SSD 100 cm	10 cm	10 cm	10x10	-
	SSD 110 cm	10 cm	10 cm	10x10	-
Wedge	SAD 100 cm	10 cm	10 cm	10x10	wedge 15
	SAD 100 cm	10 cm	10 cm	10x10	wedge 30
	SAD 100 cm	10 cm	10 cm	10x10	wedge 45
	SAD 100 cm	10 cm	10 cm	10x10	wedge 60

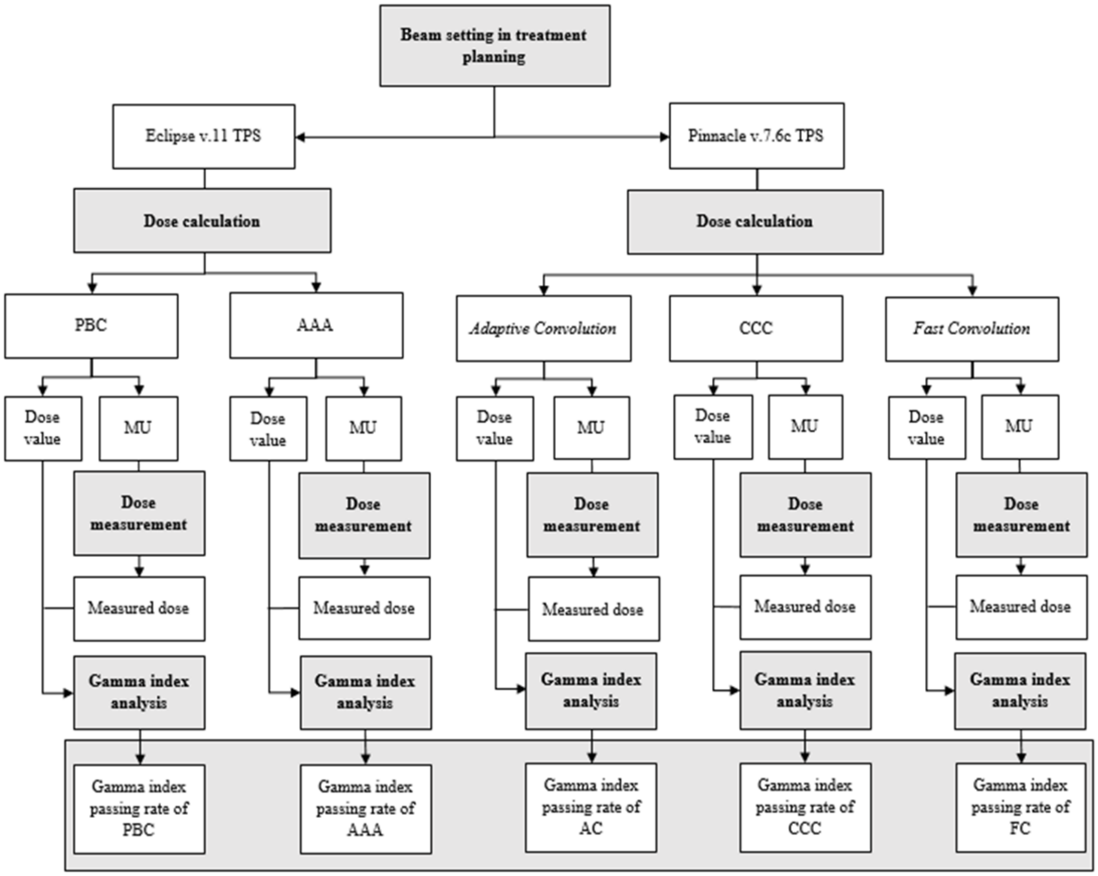

Fig. 1. Flowchart of research methodology.

RESULTS AND DISCUSSION

The comparison of central axis dose

The point dose measurement by FC65-G ionization chamber shows a dose of 78.95 ± 0.05 cGy at a reference point in field size of 10 x 10 cm^2 with SAD 100 cm and 100 MU, whereas the measurement by MatriXX Evolution shows a dose of 79.00 ± 0.05 cGy and PTW 2D-array seven29 shows a dose of 77.90 ± 0.00 cGy. It indicates that the measurements of those detector arrays are close to the measurement of the FC65-G ionization chamber.

Gamma index analysis

This study generated some data from PBC and AAA with MatriXX Evolution detector (PBC MatriXX and AAA MatriXX), PBC and AAA with PTW 2D-array seven29 detector (PBC PTW and AAA PTW), FC, AC, and CCC with PTW 2D-array seven29 detector. PBC PTW was compared to PBC MatriXX as well as AAA PTW was compared to AAA MatriXX. This comparison was done to determine the consistency in dose calculation with different detectors. Besides, PBC PTW and AAA PTW was also compared to FC, AC, and CCC which were evaluated by the same detector to eliminate the systematic error.

Figure 2 shows the passing rates of each algorithm for various field sizes and gamma criteria. Both of the detectors show that passing rates of AAA are higher than those of PBC, consistently, except for field size of 5 x 5 cm^2. It indicates that AAA is more accurate than PBC.

PBC has not separated the modeling for primary photons, scattered extra-focal photons, and scattered electrons so the heterogeneities correction is still limited, while AAA as a 3D pencil beam convolution-superposition algorithm accounts tissue heterogeneities anisotropically in the full 3D neighborhood by the use of lateral photon scatter kernels and already separate the primary and secondary components of radiation [11-13]. The comparison of the same detector shows that the convolution algorithms which have separated primary-secondary components and take 3D sample are more superior than PBC in many criteria except for 3 %/2 mm. It means that PBC calculates dose distribution more accurately in high gradient dose area.

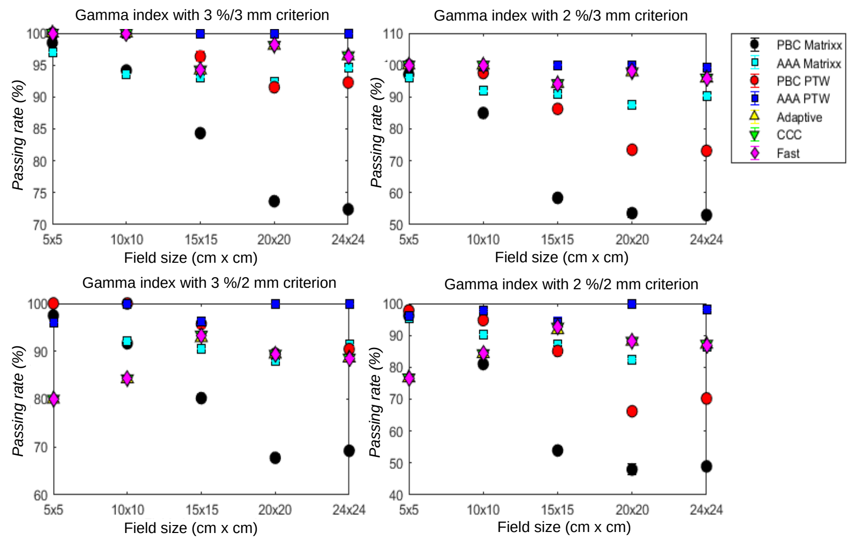

Fig. 2. Graphs of gamma index passing rates for various field sizes and gamma criteria.

AAA PTW, which has the highest passing rates, has the lowest *CL*. The *CL* is 0.00 % (100.00 % passing), 1.01 % (98.99 % passing), 5.49 % (94.51 % passing), and 7.07 % (92.93 % passing) for 3 %/3 mm, 2 %/3 mm, 3 %/2 mm, and 2 %/2 mm, respectively. The *CL* 0.00 % means that there is 95 % probability for all points dealing with the criterion. Moreover, the *CL* 1.01 % means that there is 95 % probability for the passing rate more than 98.99 %. Compared to the action levels recommended by Crowe et al., the result of this case shows that some passing rates are lower, such as PBC in field sizes of 20 x 20 cm^2 and 24 x 24 cm^2 for 2 %/3 mm and 2 %/2 mm, and convolution algorithms in field size of 5 x 5 cm^2 for 3 %/2 mm.

Gamma index analysis for various depth doses

Figure 3 shows the passing rates of each algorithm for various depth doses and gamma criteria. The measurements using MatriXX Evolution at depths of 1 cm and 5 cm give different comparison of PBC and AAA. The area of 1 cm depth which is the buildup region has high dose with high dose gradient, whereas the area of 5 cm depth which is the inner region has high dose with low dose gradient and still receives much scatter [4]. The dose calculation of AAA shows an undulated surface of the dose profile because of its accuracy in accounting the air in the ionization chambers as the heterogeneous medium, while the dose profile of PBC has flat surface. Based on Hussein study, Verisoft interpolates the evaluated dose distribution into finer grid spacing [14]. The interpolation will not show an undulated dose profile so the passing rates of AAA becomes underestimated, while the passing rates of PBC will not be affected by the interpolation and have the real passing rates. In the other side, OmniPro does not run the interpolation, so the passing rates of AAA are not underestimated. The interpolation explains why the passing rates of AAA with PTW 2D-array seven29 detector are lower than those of PBC and the contrary results are obtained by MatriXX Evolution.

The comparison of the passing rates of PBC and AAA must be evaluated from OmniPro for the passing rates are not underestimated. It means that AAA is more superior than PBC for dose calculation in various depths. The dose profile of the convolution algorithms also has flat surface in buildup and inner regions, so their passing rates can be compared to those of PBC. Since the convolution algorithms' passing rates are lower than the PBC's, the convolution algorithms are less accurate in calculating at those regions. In other words, this case also proved that AAA is the most accurate.

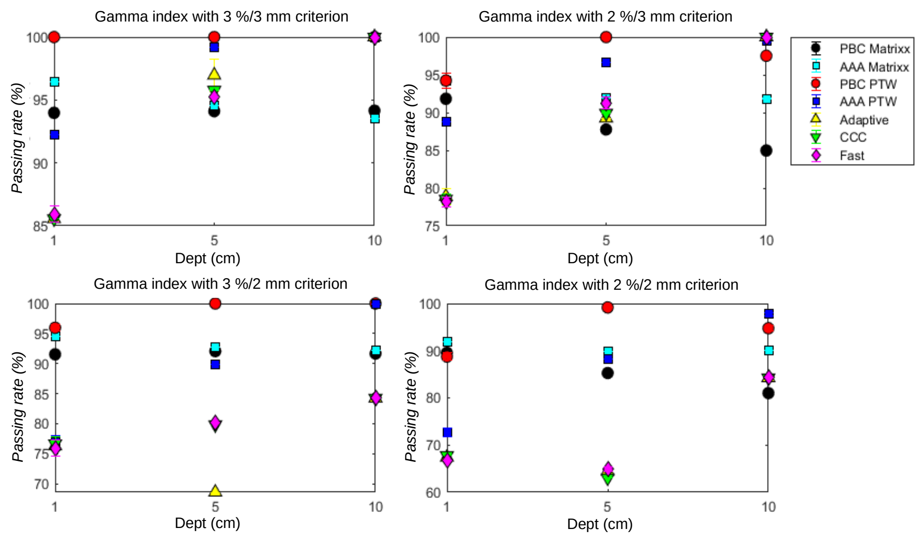

Fig. 3. Graphs of gamma index passing rates for various depths and gamma criteria.

Gamma index analysis for various SSDs

Figure 4 shows passing rates of each algorithm for various SSDs and gamma criteria which all are more than the action level. The passing rates of the convolution algorithms with criterion of 2 %/3 mm are higher than those of 3 %/2 mm. However, the passing rates of PBC PTW with criterion of 3 %/2 mm are higher than those of 2 %/3 mm. It indicates that convolution algorithms work better with dose deviation than distance-to-agreement (DTA) while PBC with DTA. The result of this case agrees with that of two previous cases, which shows that dose calculation with PBC is more accurate than the convolution algorithms in high gradient dose area.

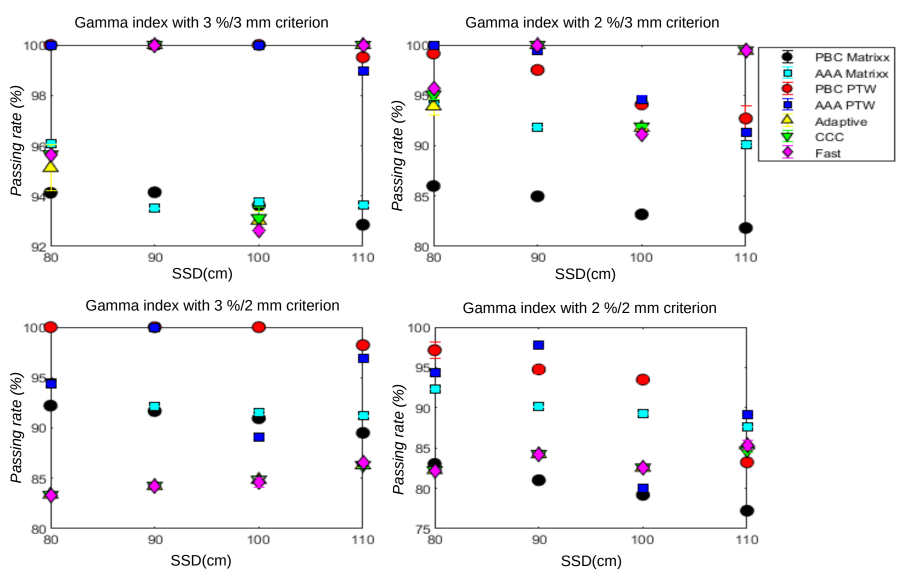

Fig. 4. Graphs of gamma index passing rates for various SSDs and gamma criteria.

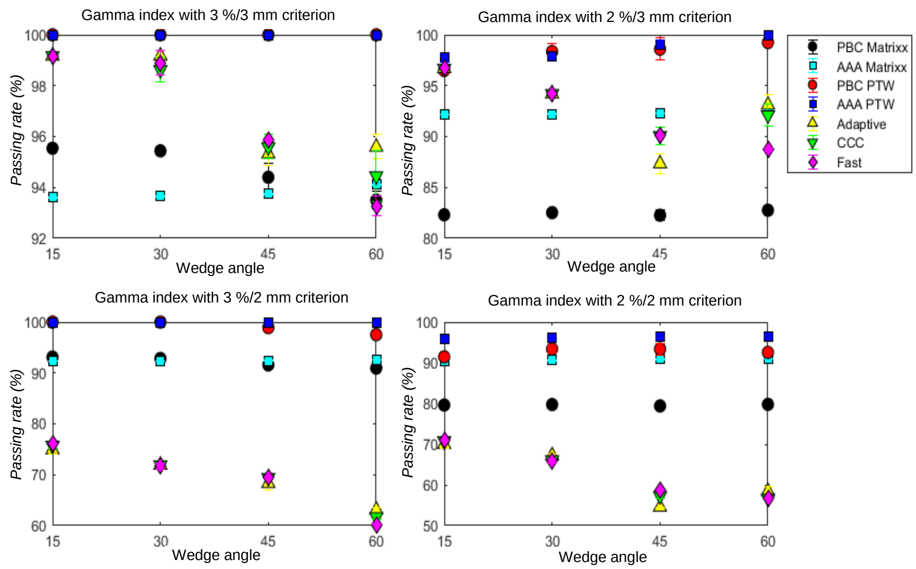

Fig. 5. Graphs of gamma index passing rates for various wedge angles and gamma criteria.

Gamma index analysis for various wedge angles

Figure 5 shows passing rates of each algorithm for various wedge angles and gamma criteria. Passing rates of convolution algorithms used physical wedge (PW), and PBC used enhanced dynamic wedge (EDW). The results describe that the passing rates tend to decrease with increasing wedge angles in general. Whereas, AAA which used EDW tends to increase slightly. In the using of EDW, PBC calculates the dose distribution by superposition of many rectangular fields without accounting for extra-focal radiation so the high dose gradient region could be failed in many criteria, while AAA models opened field with accounting for scatter factor [15,16]. It explains why the passing rates in Fig. 4 show that AAA calculates dose more accurately than PBC does. The passing rates of convolution algorithms which are less than the action level for criterion of 3 %/2 mm explain that those algorithms do not agree with DTA for PW included calculating dose.

Gamma index analysis final results

Overall, passing rates of the three convolution algorithms are almost similar. It is caused by the homogeneity of the medium. Passing rate of PBC PTW is higher than passing rate of PBC MatriXX. Besides, the passing rate of AAA PTW is higher than passing rate of AAA MatriXX. This result supports Hussein study which compared Verisoft and OmniPro to Matlab with and without interpolation. The study showed that Verisoft dealt with Matlab interpolation and had higher passing rate [14].

Table 3. Means, standard deviation *σ*, and *CL* of overall passing rates for each algorithm and gamma criterion.

Criterion	Algorithm	*mean*	*σ*	*CL*	*passing*
3 %/3 mm	PBC MatriXX	91.19 %	7.47 %	23.45 %	76.55 %
	AAA MatriXX	94.20 %	1.24 %	8.24 %	91.76 %
	PBC PTW	98.73 %	2.76 %	6.69 %	93.31 %
	AAA PTW	99.40 %	1.89 %	4.31 %	95.69 %
	AC	96.79 %	3.75 %	10.55 %	89.45 %
	CCC	96.67 %	3.74 %	10.65 %	89.35 %
	FC	96.59 %	3.77 %	10.80 %	89.20 %
2 %/3 mm	PBC MatriXX	79.84 %	12.71 %	45.08 %	54.92 %
	AAA MatriXX	91.98 %	1.88 %	11.70 %	88.30 %
	PBC PTW	93.64 %	8.49 %	23.00 %	77.00 %
	AAA PTW	97.71 %	3.30 %	8.75 %	91.25 %
	AC	94.54 %	5.64 %	16.51 %	83.49 %
	CCC	94.75 %	5.50 %	16.02 %	83.98 %
	FC	94.57 %	5.70 %	16.59 %	83.41 %
3 %/2 mm	PBC MatriXX	88.40 %	8.30 %	27.87 %	72.13 %
	AAA MatriXX	92.31 %	1.78 %	11.19 %	88.81 %
	PBC PTW	97.90 %	3.36 %	8.68 %	91.32 %
	AAA PTW	96.21 %	6.15 %	15.84 %	84.16 %
	AC	80.08 %	8.44 %	36.46 %	63.54 %
	CCC	80.87 %	7.99 %	34.79 %	65.21 %
	FC	80.74 %	8.25 %	35.43 %	64.57 %
2 %/2 mm	PBC MatriXX	76.43 %	13.53 %	50.10 %	49.90 %
	AAA MatriXX	89.74 %	2.82 %	15.79 %	84.21 %
	PBC PTW	89.76 %	9.25 %	28.37 %	71.63 %
	AAA PTW	93.18 %	7.21 %	20.96 %	79.04 %
	AC	76.80 %	11.24 %	45.23 %	54.77 %
	CCC	76.79 %	11.25 %	45.27 %	54.73 %
	FC	76.94 %	11.05 %	44.72 %	55.28 %

According to Table 3, AAA has the highest passing rate and the lowest *CL*, followed by PBC, and then convolution algorithms. For 2 %/2 mm as the tightest criterion, AAA has the highest passing rate which is 93.18 % ± 7.21 % and the lowest *CL* which is 20.96 % (79.04 % passing), followed by PBC with 89.76 % ± 7.21 % passing rate and 28.37 % (71.63 % passing) *CL*, then convolution algorithms with 76.84 % ± 11.10 % passing rate and 44.90 % (55.10 % passing) *CL*.

Central axis dose deviation analysis

The value of central axis dose can be obtained to evaluate the dose deviation at one measurement point. Dose deviation of the algorithms from the lowest to the highest are FC (0.85 % ± 1.06 %), AAA (0.91 % ± 1.38 %), CCC (1.30 % ± 1.34 %), AC (1.34 % ± 1.36 %), and PBC (7.81 % ± 1.17 %). The high deviation of PBC is caused by the lower MU of PBC while other algorithms generated approximate values of MU. The PBC's deviation contradicts with its passing rate. High passing rate indicates high accuracy so dose deviation is supposed to be low. The contradiction could be happened because the planar doses were normalized to their own central point, instead of central point of measured planar dose as the reference in gamma index analysis. In other words, the accuracy from gamma index analysis result refers to the accuracy of dose distribution calculation. The evaluation of the accuracy of point dose calculation is better from dose deviation which is related to MU calculation accuracy.

The consideration of other used parameters

In this research, the authors used the same parameters for different equipment, such as CT slice thickness 2 mm with 120 kV and 250 mAs per slice, planar dose normalization at a central point, and low dose threshold 5 % of the maximum dose. The error caused by the parameters has been anticipated even though it has not shown the best result [17]. Another factor that influences the passing rate is planar dose resolution [18-20]. Eclipse v.11 can export planar dose with a resolution of 0.059 in a short time, while Pinnacle[3] v.7.6c takes a long time to export small resolution planar dose. The authors also compared the passing rates from Pinnacle[3] v.7.6c planar dose with resolution of 0.20 cm, 0.25 cm, and 0.50 cm. The highest passing rate is achieved by the resolution of 0.25 cm, followed by the resolution of 0.50 cm, and then the resolution of 0.20 cm. The authors used the resolution of 0.50 cm for the efficiency of time and acceptable result.

CONCLUSION

The central axis dose deviation analysis shows that AAA and convolution algorithms have low dose deviations which indicates high accuracy of central point dose calculation, whereas PBC has high dose deviation due to the lower MU which indicates low accuracy. On the contrary, gamma index analysis shows that PBC has high accuracy of dose distribution calculation as the passing rates of PBC are comparable to those of other algorithms. For this issue, the MU analysis for each algorithm should be more explored in the further research.

The gamma index analysis is used to evaluate the accuracy of the dose distribution calculation. Among the algorithms used in this research, AAA with the highest passing rates, does the most accurate dose distribution calculation. For gamma criterion of 2 %/2 mm, passing rate of AAA was 93.18 % ± 7.21 %, where passing rate of PBC and convolution algorithm are 89.76 % ± 7.21 % and 76.84 % ± 11.10 %, respectively. Furthermore, the passing rates of three convolution algorithms which are almost similar to each other, are lower than those of PBC in case related to high gradient dose area. In other words, dose calculation with PBC is more accurate than the convolution algorithms in that area. This research also found that gamma index analysis with OmniPro ImRT for dose distribution in high gradient dose area is more accurate since it does not run the interpolation for the measured planar dose. The new version of the gamma index analysis software and algorithms can be used for further research.

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