

Evaluation of Various Resolutions for Optimization and Dose Calculation in VOLO™ Ultra of the Tomo Therapy Treatment Planning System

Sirirad Tongta^{1,2}, Anirut Watcharawipha² , Wannapha Nobnop² , Somsak Wanwilairat²  and Warit Thongsuk² 

¹Medical Physics Program, ²Division of Radiation Oncology, Department of Radiology, Faculty of Medicine, Chiang Mai University, Chiang Mai, Thailand

Correspondence:

Anirut Watcharawipha, PhD,
Division of Radiation Oncology,
Faculty of Medicine, Chiang Mai
University. 110 Inthavarorot Rd,
Tambon Si Phum, Amphur Muang,
Chiang Mai, 50200, Thailand.
E-mail: anirut.watch@cmu.ac.th

Received: 26 September, 2024;

Revised: December 14, 2024;

Accepted: January 7, 2025

ABSTRACT

OBJECTIVE Helical tomotherapy can deliver a radiation dose using modulated intensity. This delivery technique requires inverse treatment planning for dose distribution. The specific parameters include the resolution of optimization and dose calculation. The highest resolution provided a high plan quality in a previous study, but that plan would increase the calculation time. This study investigated the quality of plans using various resolutions of optimization and dose calculation in VOLO™ Ultra. The exploration aimed to determine the optimal resolution to inform the treatment planning process in nasopharyngeal carcinoma (NPC).

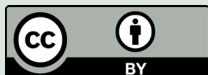
METHODS Forty-one cases of NPC who had been previously treated using helical therapy were randomly recruited between January 2022 and December 2023. Nine treatment planning scenarios were created using the VOLO™ Ultra planning system using a combination of optimization and calculated resolution. Three different levels of resolutions were chosen: high (H), medium (M) and low (L). The different resolution combinations were expressed as, e.g., H/H for high resolution optimization and dose calculation. The dosimetric parameters of the planning target volumes (PTVs), organs at risk (OARs), and plan quality index, such as dose coverage ($D_{98\%}$, Dose at 98% target volume), conformity index (CI) and homogeneity index (HI), were evaluated.

RESULTS The PTVs revealed an increasing dose value when the dose calculation resolution was increased. In contrast, the study found an increasing dose value when the resolution was decreased. A similar trend was also found in the conformity index value in the optimization process. The OARs demonstrated similar dose levels, with the exception of the spinal cord and both parotid glands.

CONCLUSIONS This study illustrates that the resolution of M/H and M/M scenarios is a specific choice of interest. These scenarios provide higher dose coverage, have a mild impact on OAR dose, a moderate impact on conformity and a shorter treatment planning time.

KEYWORDS tomotherapy, dose optimization, dose calculation, nasopharyngeal carcinoma, resolution

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INTRODUCTION

Radiotherapy in the head and neck region (H&N) presents a significant challenge for treatment planning. The complexity of treatment planning is heightened by the proximity of critical organs such as the brainstem, parotids, and spinal cord to target area. For those reasons, intensity modulated radiotherapy (IMRT) plays a crucial role (1) in sparing normal organs (2) while delivering the prescribed dose to the target. Inverse planning (3) is necessary for this treatment technique, which requires dose constraints, photon fluence optimization and dose calculation. Tomotherapy is a treatment modality that provides intensity modulation using both a static gantry IMRT and a rotating gantry (Intensity Modulated Arc Therapy, IMAT). By utilizing a Binary Multi-Leaf Collimator (BiMLC) and overlapping helical fan beam rotation (helical tomotherapy, HT), this treatment offers beneficial beam modulation diversity (4).

When employing HT, the treatment planning system (TPS) requires specific parameters consisting of a field width (FW), a pitch factor (PF), and a modulation factor (MF) (5). FW is the width of the radiation fan beam which can be selected based on the length of the target. PF can be determined by couch travel/FW. This parameter can be specified by the irregular shape of the target. In MF, this parameter is calculated by the ratio of the maximum leaf open time and the average leaf open time. The value of MF depends on the shape and location of the target. These parameters can improve the plan quality, particularly in the case of cancers in the H&N region. Treatment planning can be performed using two platforms in this TPS: the Classic treatment planning platform and the VOLO™ Ultra platform. The VOLO™ Ultra uses fewer specific parameters than the classic platform to create a treatment plan, e.g., there is no PF or MF requirement. Using the VOLO™ Ultra platform is convenient and user friendly, especially for nasopharyngeal carcinoma (NPC) treatment planning. However, there are other parameters that are required in both platforms, including the grid spacing or resolution of dose optimization and the dose calculation for each plan, both of which might impact plan quality. Although previous publications (5-10) have reported on the impact of resolution in dose optimization and dose calculation, this impact has not yet been

demonstrated in tomotherapy, particularly VOLO™ Ultra treatment planning. The resolution in tomotherapy TPS can be selected from four different levels; however, the selection is also dependent on the size of the field of view (FOV). The resolution of HT is classified not only by an image pixel number, e.g., very low (64×64 pixels), low (128×128 pixels), medium (256×256 pixels) and high (512×512 pixels), but is also determined by the FOV/image pixel number, e.g. 500/512 or 600/512. For a high quality treatment plan, it is necessary to determine appropriate values for treatment parameters (11) and to use the highest resolution of the optimization and dose calculation. Although the central processing unit (CPU) technology has been highly developed, choosing the highest resolution may increase the computational time (5-7, 12).

By various the resolution in the optimization and dose calculation, this study aimed to investigate the impact of different resolution levels on plan quality and to determine the optimal resolution selection, including the optimal FOV for NPC. While there are four resolution levels available, this study focused on three levels: low, medium and high resolution, for both fluence optimization and dose calculation.

METHODS

Ethical clearance

This retrospective study recruited 41 NPC patients who had been treated between January 2022 and December 2023 and included 31 males and 10 females. The research proposal was approved by the Research Ethics Committee of the Faculty of Medicine at Chiang Mai University (Study code: RAD-2566-0556) in November 2023.

Patient selection and data preparation

The helical tomotherapy treatment plans for the 41 NPC patients were randomly selected during the period January 2022 through December 2023. All the treatment plans had been performed on computed tomography (CT) image sets acquired by a CT simulator (SOMATOM definition AS, Siemens Healthineers, Inc., Erlangen, Germany). Although the slice thickness of the image set was set at 3 mm, the size of FOV was harmonized with the body of the patients. In this study, the image planning acquisition had 3 sizes of FOV, specifically, 500

mm, 550 mm and 650 mm. The S-type thermo-plastic mask (Klarity White™, Klarity®, Guangzhou, China) was used for the immobilization of all the selected cases.

All recruited treatment plans consisted of three planning target volumes (PTVs) at dose levels of 70.0 Gy, 59.4 Gy and 54.0 Gy. These zones were expanded by 5 mm from the clinical target volume (CTV). In cases of skin involvement with the CTV, the PTVs were cropped by 3 mm from the surface. The simultaneous integrated boost (SIB) technique was employed on all PTVs across 33 fractions. Other structures and organs at risk (OARs), considered in the radiation dose plan included the brainstem, spinal cord, parotid glands, optic chiasm, optic nerves and globes.

Treatment planning scenarios

All treatment plans were replanned using the TPS of Tomotherapy (Precision® version 3.3.0.1, Accuray Inc., Sunnyvale, California, USA). Although the previous plans had been performed, they were re-optimized and re-dose calculated utilizing the VOLO™ Ultra (Precision® version 3.3.0.1, Accuray Inc., Sunnyvale, California, USA). The treatment plans were created in 9 scenarios by a single planner, which were a combination of various resolutions of optimization and dose calculations. The resolution of the previous treatment plan was selected as the template for a new treatment plan, including the beam geometries such as treatment techniques, FW, etc. The treatment plans for each patient then had nine scenarios with different combinations of resolution between fluence optimization and dose calculation. The resolution of the optimization and dose calculation (Opt/Cal) varied between high-resolution (H), medium-resolution (M) and low-resolution (L). The abbreviation of each scenario is expressed as H/H for high-resolution optimization/high-resolution dose calculation, M/L for medium-resolution optimization/low-resolution dose calculation, etc. Using the VOLO™ Ultra, the treatment system automatically calculated the optimum PF and MF. Although the PF was calculated automatically, the value was then fixed in all treatment scenarios for each case. Only the MF could not be adjusted using this option. These plan parameters are summarized in Table 1.

The constraints of the targets followed the guidelines of the International Commission on

Radiation Units and Measurements (ICRU) number 83 (13), specifically: 1) 98% of the target volume received at least 95% of the prescribed dose ($D_{98\%} \geq 95\%$ of the prescribed dose), 2) the prescribed dose was delivered to 50% of the target volume ($D_{50\%} =$ prescribed dose) and 3) less than 107% of the prescribed dose was delivered to 2% of the target volume ($D_{2\%} \leq 107\%$ of the prescribed dose). However, the structures of PTV_{59.4} contained the PTV_{70.0} and were superior to the isolated structure of PTV_{54.0}. The dose of $D_{2\%}$ was then constrained only on the PTV_{70.0}. Table 2 summarizes the dose constraints both for the targets and also for each organ of OAR.

Dosimetric parameters, indexes and planning time

All treatment plan scenarios were evaluated regarding targets and the OARs by dosimetric parameters and indexes. The indexes were evaluated regarding the PTV which consisted of a

Table 1. Mean, standard deviation (SD) of patient characteristics and treatment planning parameters in tomotherapy

PTV size (cc)	
PTV70.0 Gy	209.41 (95.23)
PTV59.4 Gy	639.19 (145.13)
PTV54.0 Gy	138.20 (82.14)
Pitch	0.41 (0.06)
Modulation factor	1.49 (0.22)
Field width (mm)	4.39 (1.09)
Field of view (mm)	600 (55.90)

PTV, planning target volume

Table 2. Dose constraints of target and organs at risk of nasopharyngeal carcinoma

Structures	Parameter	Dose constraints
Target		
PTV _{70.0}	$D_{98\%}$	$\geq 95\%$ of prescribed dose
	$D_{50\%}$	= prescribed dose
	$D_{2\%}$	$\leq 107\%$ of prescribed dose
PTV _{59.4}	$D_{98\%}$	$\geq 95\%$ of prescribed dose
	$D_{50\%}$	= prescribed dose
PTV _{54.0}	$D_{98\%}$	$\geq 95\%$ of prescribed dose
	$D_{50\%}$	= prescribed dose
Organs at risk		
Brainstem	$D_{2\%}$	≤ 54 Gy
Spinal cord	$D_{2\%}$	≤ 45 Gy
Optic chiasm	$D_{2\%}$	≤ 54 Gy
Optic nerve	$D_{2\%}$	≤ 54 Gy
Parotid	$D_{50\%}$	≤ 30 Gy
Globe	D_{mean}	≤ 35 Gy

PTV, planning target volume

conformity index (12) (CI_{ICRU}) and a homogeneity index (12) (HI). The CI_{ICRU} and HI were employed using the ICRU no. 83 formula as recommended. The CI_{ICRU} was calculated by PIV/PTV , where PIV is the prescribed isodose volume. The HI was calculated by $(D_{2\%} - D_{98\%})/D_{50\%}$ where $D_{x\%}$ is the dose level at x% volume. Other structures for evaluation were the OARs. The dose constraints described in Table 2 were normalized on the organs in the treatment plan scenarios as an evaluation tool.

Treatment planning time was also used to compare the computation time of the plan scenarios. However, this measurement was not included in the time of dose constraints adjustment of each organ. The optimization was set at 20 iterations per round for each of 3 rounds. The dose calculation time was then added to the time of the optimization process.

Statistical analysis

Statistical analysis was conducted using SPSS version 27.0.1 (IBM SPSS Statistics, IBM Co., Armonk, New York, USA). This analysis assessed the significant differences between the plan quality parameters and dosimetric indexes, CI_{ICRU} and HI, of PTVs as well as the dose levels on the OARs.

The planning time and the differences in FOV were also analyzed. The Shapiro-Wilk test was employed to assess the normality of the data. A Wilcoxon sign-rank test was used for significant difference analysis between the highest resolution scenario (H/H resolution scenario) and each of the others at a 95% confidence interval ($p < 0.05$).

RESULTS

The results of the various resolutions and the optimization and dose calculations of the treatment planning were assembled. The results were classified in terms dosimetric parameters of the target and OARs, treatment planning time and dosimetric parameters of various FOV.

Dosimetric parameters on the targets and OARs

The dosimetric parameters of the $PTV_{70.0}$, $PTV_{59.4}$ and $PTV_{54.0}$ are reported in Table 3. The values are expressed as mean percentage dose difference (standard deviations: SD) compared to dose constraints. The relative values of the nine scenarios were normalized by the dose constraints as listed in Table 2. Figure 1 shows the plots of PTV dosimetric results of all scenarios.

Table 3. Mean percentage dose difference (SD) compared to dose constraint of target parameters in various resolutions of optimization and dose calculation.

Target	Parameter	Optimization/calculation resolution scenario (%)								
		H/H	H/M	H/L	M/H	M/M	M/L	L/H	L/M	L/L
PTV ₇₀	D _{2%}	96.92 (0.74)	96.54 (0.73)	95.98 (0.77)	97.21 (0.68)	96.78 (0.67)	96.16 (0.68)	97.88 (0.70)	97.42 (0.66)	96.73 (0.72)
	D _{50%}	100.64 (0.46)	100.46 (0.43)	100.03 (0.50)	100.98 (0.43)	100.79 (0.44)	100.35 (0.43)	101.24 (0.44)	101.5 (0.42)	100.64 (0.42)
	D _{98%}	97.84 (5.44)	97.51 (5.36)	96.69 (5.16)	98.30 (5.53)	98.01 (5.45)	97.19 (5.23)	98.34 (5.62)	98.12 (5.54)	97.49 (5.37)
CI		15.42 (9.04)	14.20 (10.46)	9.70 (9.46)	19.30 (11.75)	16.89 (11.26)	11.79 (10.21)	26.09 (13.87)	23.54 (13.43)	18.56 (12.27)
	HI	10.71 (5.09)	10.61 (5.03)	10.84 (4.78)	10.53 (5.16)	10.37 (5.07)	10.53 (4.84)	11.17 (5.28)	10.91 (5.17)	10.81 (4.95)
PTV _{59.4}	D _{50%}	105.15 (4.11)	104.94 (4.04)	104.49 (3.93)	105.49 (4.25)	105.24 (4.18)	104.76 (4.00)	106.31 (4.33)	106.05 (4.25)	105.53 (4.14)
	D _{98%}	100.17 (1.30)	99.84 (1.36)	98.96 (1.43)	100.77 (1.24)	100.50 (1.38)	99.62 (1.44)	100.61 (1.34)	100.23 (1.86)	99.78 (1.49)
PTV ₅₄	D _{50%}	100.36 (0.51)	100.14 (0.52)	99.72 (0.56)	100.54 (0.76)	100.44 (0.46)	100.00 (0.46)	100.83 (0.53)	100.66 (0.53)	100.21 (0.58)
	D _{98%}	101.68 (1.00)	101.35 (1.16)	100.39 (1.30)	102.48 (1.15)	102.16 (1.15)	101.15 (1.20)	102.27 (0.94)	102.11 (1.03)	101.48 (1.13)

H, high resolution; M, medium resolution; L, low resolution; PTV, planning target volume; CI, conformity index; HI, homogeneity index and Dx%, dose at x% volume

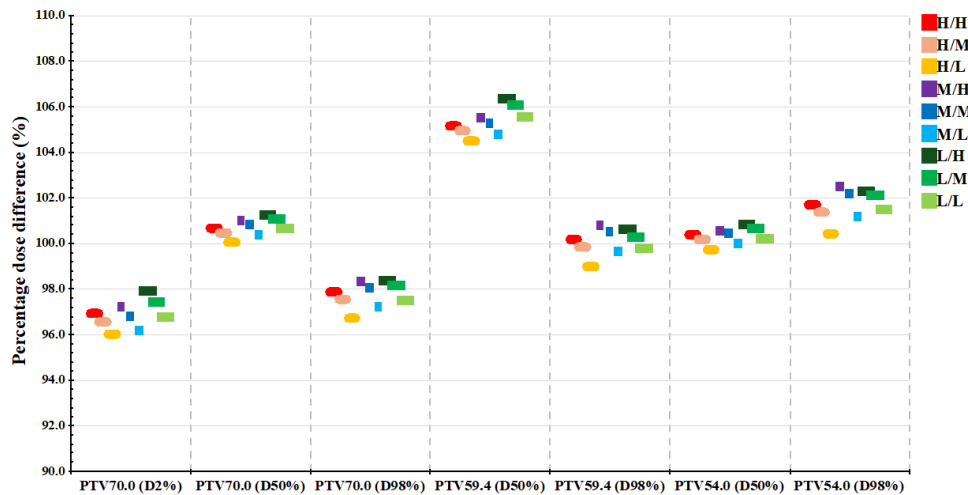


Figure 1. Mean percentage dose difference compared to the dose constraint of PTVs dosimetric parameters in various resolutions of optimization and dose calculation

Table 4. Statistical analysis (p -value) of target dosimetric parameters in various resolutions of optimization and dose calculation using the highest resolution scenario (H/H resolution scenario) benchmark

Target	Parameter	Optimization/calculation resolution scenario (%)								
		H/H	H/M	H/L	M/H	M/M	M/L	L/H	L/M	L/L
PTV ₇₀	D _{2%}	Benchmark	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p = 0.004$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$
	D _{50%}		$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	-
	D _{98%}		$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$
	CI		$p < 0.001$	$p < 0.001$	$p < 0.001$	$p = 0.015$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$
	HI		$p < 0.001$	$p < 0.001$	$p = 0.008$	$p < 0.001$	$p = 0.024$	$p < 0.001$	$p < 0.001$	$p = 0.014$
PTV _{59.4}	D _{50%}		$p < 0.001$	$p < 0.001$	$p < 0.001$	-	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$
	D _{98%}		$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p = 0.001$	$p < 0.001$
PTV ₅₄	D _{50%}		$p < 0.001$	$p < 0.001$	$p < 0.001$	$p = 0.024$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$
	D _{98%}		$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p = 0.007$

H, high resolution; M, medium resolution; L, low resolution; PTV, planning target volume; CI, conformity index; HI, homogeneity index and Dx%, dose at x% volume

p -value was expressed only the data that had p -value less than 0.05

At the PTV_{70.0}, all scenarios had a mean percentage dose difference of D_{2%} lower than 100%. This means that all plans had a high dose lower than 2% of PTV_{70.0}. In comparison, all scenarios showed a significant difference when compared to the highest resolution scenario ($p \leq 0.004$). At the target dose, the D_{50%} of PTVs had a value of over a hundred percent which shows all PTVs received the prescribed dose, with the exception of the PTV_{54.0} in the H/L scenario. Although PTV_{54.0} in this scenario received a dose lower than the prescription, the range of prescribed doses was acceptable. The dosimetric parameters were statistically analyzed as shown in Table 4. This analysis demonstrated a significant difference between the H/H scenario and all scenarios of PTV_{70.0} ($p <$

0.004), PTV_{59.4} ($p \leq 0.001$) and PTV_{54.0} ($p \leq 0.024$), with the exception of the L/L scenario of PTV_{70.0} and M/M scenario of PTV_{59.4}. These results revealed a percentage of D_{98%} lower than a hundred in all scenarios of PTV_{70.0} and PTV_{54.0}. On the other hand, the PTV_{59.4} received a dose of D_{98%}, lower than the hundred in the H/M, H/L, M/L and L/L scenarios. Statistical analysis showed a significant difference among all scenarios of PTV_{70.0} ($p < 0.004$), PTV_{59.4} ($p \leq 0.001$) and PTV_{54.0} ($p \leq 0.007$).

The CI_{ICRU} and HI were also observed in this study. The percentages are presented in Figure 2a. The results show the lowest and highest values of CI_{ICRU} in the H/L and L/H scenarios, respectively. On the HI, the lowest value was the M/M scenario, whereas the highest value was the L/H

Table 5. Mean percentage dose difference (SD) compared to dose constraint of organs at risks parameters in various resolutions of optimization and dose calculation

Organs at risk	Parameter	Optimization/calculation resolution scenario (%)								
		H/H	H/M	H/L	M/H	M/M	M/L	L/H	L/M	L/L
Brainstem	D _{2%}	91.28 (9.76)	91.29 (9.65)	91.43 (9.44)	91.59 (9.75)	91.55 (9.65)	91.68 (9.40)	92.13 (10.18)	92.05 (10.15)	92.09 (9.94)
Spinal cord	D _{2%}	68.01 (12.27)	68.48 (12.09)	69.93 (12.20)	67.92 (12.20)	68.45 (12.37)	69.70 (12.35)	66.13 (13.21)	66.48 (13.28)	67.66 (13.27)
Lt parotid	D _{50%}	105.95 (37.71)	106.97 (36.94)	108.92 (35.46)	105.88 (38.06)	106.94 (37.23)	108.23 (35.52)	106.13 (38.86)	107.08 (38.05)	108.91 (36.49)
Rt parotid	D _{50%}	104.18 (37.33)	105.26 (36.68)	107.26 (35.40)	104.56 (37.56)	105.46 (37.05)	108.07 (35.85)	104.32 (39.20)	105.43 (38.56)	107.38 (37.22)
Optic chiasm	D _{2%}	74.56 (32.90)	75.03 (32.97)	74.63 (33.30)	74.58 (32.76)	74.82 (32.94)	75.44 (33.36)	74.48 (32.87)	73.71 (32.85)	74.93 (33.26)
Lt optic nerve	D _{2%}	79.07 (30.38)	79.38 (30.53)	79.86 (30.82)	78.78 (30.16)	79.09 (30.32)	79.69 (30.67)	79.10 (30.53)	79.28 (30.54)	79.48 (30.69)
Rt optic nerve	D _{2%}	77.32 (28.72)	77.69 (28.87)	78.32 (29.17)	76.06 (29.07)	77.76 (28.78)	78.24 (29.01)	77.75 (29.02)	77.79 (29.04)	78.04 (29.10)
Lt globe	D _{mean}	37.81 (20.00)	37.97 (20.18)	38.28 (20.34)	38.08 (20.35)	38.28 (20.42)	38.64 (20.60)	36.45 (19.38)	36.59 (19.42)	37.02 (19.63)
Rt globe	D _{mean}	38.02 (17.73)	38.32 (17.75)	38.66 (17.91)	38.19 (17.69)	38.33 (17.74)	38.80 (17.92)	37.27 (17.34)	37.44 (17.37)	37.83 (17.52)
Opt and calc time	Sec	377.35 (96.99)	337.94 (90.69)	328.38 (89.26)	161.37 (49.60)	121.89 (38.21)	110.89 (36.03)	121.89 (27.56)	80.67 (16.07)	70.92 (14.01)

H, high resolution; M, medium resolution; L, low resolution; D_{mean}, mean dose; D_{x%}, dose at x% volume; Opt, optimization and calc, calculation; Lt, left; Rt, right; Sec, second

Table 6. Statistical analysis (*p*-value) of organs at risk and time with various resolutions of optimization and dose calculation using the highest resolution scenario (H/H resolution scenario) as a benchmark

Organs at risk	Parameter	Optimization/calculation resolution scenario (%)								
		H/H	H/M	H/L	M/H	M/M	M/L	L/H	L/M	L/L
Brainstem	D _{2%}	Benchmark	-	-	<i>p</i> = 0.005	<i>p</i> = 0.014	<i>p</i> = 0.005	<i>p</i> < 0.001	<i>p</i> < 0.001	<i>p</i> < 0.001
Spinal cord	D _{2%}		<i>p</i> < 0.001	<i>p</i> < 0.001	-	<i>p</i> = 0.013	<i>p</i> < 0.001	<i>p</i> < 0.001	<i>p</i> < 0.001	-
Lt parotid	D _{50%}		<i>p</i> < 0.001	<i>p</i> < 0.001	-	<i>p</i> < 0.001	<i>p</i> < 0.001	-	<i>p</i> = 0.011	<i>p</i> < 0.001
Rt parotid	D _{50%}		<i>p</i> < 0.001	<i>p</i> < 0.001	-	<i>p</i> < 0.001	<i>p</i> < 0.001	-	<i>p</i> = 0.012	<i>p</i> < 0.001
Optic chiasm	D _{2%}		<i>p</i> = 0.036	<i>p</i> = 0.008	-	-	<i>p</i> = 0.01	-	-	-
Lt optic nerve	D _{2%}		<i>p</i> < 0.001	<i>p</i> < 0.001	-	-	<i>p</i> = 0.002	-	-	-
Rt optic nerve	D _{2%}		<i>p</i> < 0.001	<i>p</i> < 0.001	-	<i>p</i> < 0.001	<i>p</i> < 0.001	-	<i>p</i> = 0.003	<i>p</i> < 0.001
Lt globe	D _{mean}		<i>p</i> < 0.001	<i>p</i> < 0.001	-	-	<i>p</i> = 0.015	<i>p</i> = 0.002	<i>p</i> = 0.002	-
Rt globe	D _{mean}		<i>p</i> < 0.001	<i>p</i> < 0.001	-	-	<i>p</i> < 0.001	-	-	-
Opt and calc time	Sec		<i>p</i> < 0.001	<i>p</i> < 0.001	<i>p</i> < 0.001	<i>p</i> < 0.001	<i>p</i> < 0.001	<i>p</i> < 0.001	<i>p</i> < 0.001	<i>p</i> < 0.001

H, high resolution; M, medium resolution; L, low resolution; D_{mean}, mean dose; D_{x%}, dose at x% volume; Lt, left; Rt, right; Opt, optimization; Sec, second

p-value was expressed only the data that had *p*-value less than 0.05

scenario. A significant difference was found in all scenarios on both the CI_{ICRU} (*p* ≤ 0.015) and HI (*p* ≤ 0.024).

Table 5 summarizes the data on OARs expressed as mean percentage (SD) dose by the organ dose constraints normalization. Figure 3 shows the percentage dose level of the normal organs of

interest. All OARs had a percentage lower than a hundred percent. This means these OARs met the criteria of the organ dose, with the exception of both parotid glands. A significant difference in OARs was also observed as shown in Table 6. The analysis shows that there was no significant difference in the H/M and H/L (*p* > 0.05) on the

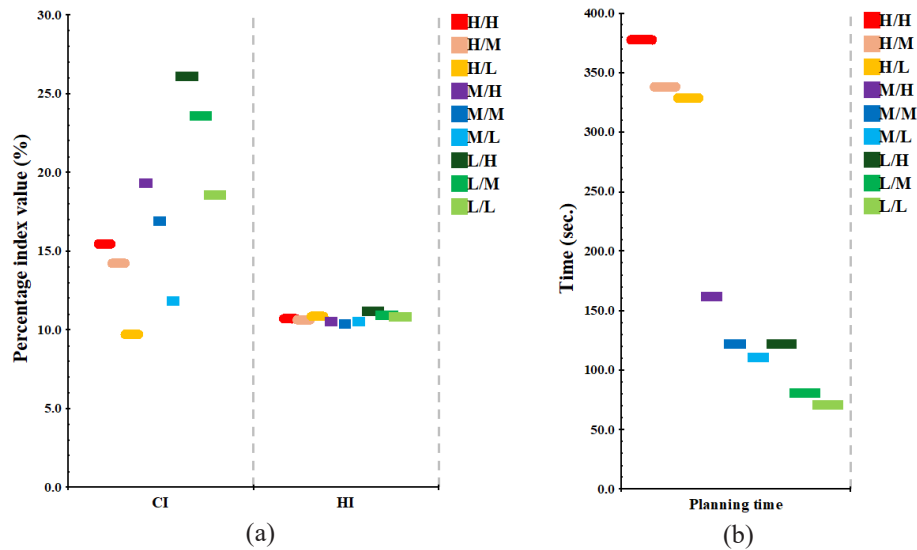


Figure 2. Percentage value difference of PTV_{70.0} dosimetric indexes and treatment planning time in various resolutions of the optimization and dose calculation. (a) Percent difference of CI_{ICRU} and HI and (b) Treatment planning time.

brainstem, whereas there was a significant difference ($p = 0.005$) in the M/H. Two scenarios, M/M and L/M, almost had a significant difference ($p \leq 0.014$) in similar organs. However, the L/M scenario showed one additional organ with a significant difference ($p = 0.002$) in the left globe. The L/H scenario showed a significant difference on the brainstem ($p < 0.001$), spinal cord ($p < 0.001$) and left globe ($p = 0.002$). The L/L scenario showed a significant difference ($p < 0.001$) regarding the brainstem, both the parotid and right optic nerve. Only the M/L scenario was significantly different on all OARs ($p \leq 0.015$).

Treatment planning time

The planning time is presented on the rows labelled Opt and Cal time in Table 5. The planning time was the longest in the highest resolution of the optimization, whereas the lowest resolution had the lowest computational time. In Table 6, The results show a significant difference ($p < 0.001$) between the highest resolution and other scenarios. The planning time in each resolution scenario is shown in Figure 2b.

Dosimetric parameters by various FOV

The mean percentage difference compared to dose constraint of the target for each FOV is summarized in Table 7. The results show that the D_{98%} of PTV_{70.0} in the FOV 500 mm provided the highest dose level, whereas the highest dose level was observed in the D_{50%} of PTV_{59.4} in the FOV 650

mm. Other dosimetric parameters showed similar results. The different dose levels for each FOV are shown in Figure 4. As shown in Table 8, for most scenarios there were no significant differences in dose parameters.

DISCUSSION

This study explored the impact of treatment plan quality using various resolutions of both dose calculation and optimization. Nine treatment plan scenarios with different resolutions were created for the investigation. In the inverse treatment planning, the photon fluence was determined in the first step (14). This compromised the photon fluence between the dose on the target and OARs as those were constraints (14). Since the constraints were accepted, the final dose calculation determined the dosage (15). This means that the photon optimization and dose calculation were separate processes, thus the resolution can differ between these two steps.

Dosimetric parameters of the targets and OARs

In PTVs, the results showed an increasing dose level when the dose calculation resolution was increasing. These results show the same pattern as those observed by Srivastava et al. (10), Kim et al. (6) and Kawashima et al. (5). In contrast, the opposite results were observed in optimization resolution. Resolutions presented with an increasing dose level when the resolution was decreased. The main impact would be raised by number of

Table 7. Mean percentage difference (SD) compared to dose constraint of target parameters in various fields of view (FOV), resolution of optimization and dose calculation

Target	Parameter	Optimization/calculation resolution scenario (%)								
		H/H	H/M	H/L	M/H	M/M	M/L	L/H	L/M	L/L
FOV 500 mm										
Opt resolution (mm)		0.98	0.98	0.98	1.95	1.95	1.95	3.91	3.91	3.91
Cal resolution (mm)		0.98	1.95	3.91	0.98	1.95	3.91	0.98	1.95	3.91
PTV ₇₀	D _{2%}	96.82	96.51	96.58	97.14	96.81	96.28	97.62	97.30	96.74
		(0.45)	(0.45)	(1.03)	(0.62)	(0.64)	(0.64)	(0.59)	(0.60)	(0.65)
	D _{50%}	100.83	100.69	100.72	101.06	100.92	100.60	101.42	101.28	100.95
		(0.22)	(0.25)	(0.84)	(0.49)	(0.49)	(0.51)	(0.20)	(0.20)	(0.24)
PTV _{59.4}	D _{98%}	100.17	99.89	99.60	100.52	100.24	99.50	100.69	100.46	99.81
		(0.60)	(0.60)	(0.31)	(0.51)	(0.44)	(0.27)	(0.79)	(0.82)	(0.90)
	D _{50%}	105.03	104.83	105.09	105.13	104.93	104.56	105.91	105.72	105.30
		(3.77)	(3.70)	(4.61)	(3.81)	(3.74)	(3.65)	(4.10)	(4.07)	(3.96)
PTV ₅₄	D _{98%}	100.39	100.15	99.80	100.84	100.64	99.94	101.05	100.86	100.32
		(0.91)	(0.82)	(0.22)	(1.07)	(0.96)	(0.81)	(1.27)	(1.20)	(1.01)
	D _{50%}	100.58	100.42	100.36	101.02	100.89	100.57	100.84	100.74	100.48
		(0.28)	(0.25)	(0.59)	(0.10)	(0.10)	(0.11)	(0.22)	(0.23)	(0.24)
	D _{98%}	102.71	102.51	102.14	103.14	102.97	102.37	103.02	102.92	102.50
		(0.70)	(0.77)	(1.40)	(1.15)	(1.22)	(1.45)	(0.47)	(0.54)	(0.81)
FOV 550 mm										
Opt resolution (mm)		1.07	1.07	1.07	2.15	2.15	2.15	4.30	4.30	4.30
Cal resolution (mm)		1.07	2.15	4.30	1.07	2.15	4.30	1.07	2.15	4.30
PTV ₇₀	D _{2%}	96.59	96.27	95.68	96.88	96.50	95.91	97.57	97.16	96.49
		(0.70)	(0.71)	(0.72)	(0.54)	(0.52)	(0.53)	(0.60)	(0.61)	(0.64)
	D _{50%}	100.56	100.40	99.98	100.83	100.65	100.27	101.11	100.95	100.56
		(0.51)	(0.50)	(0.51)	(0.44)	(0.44)	(0.45)	(0.47)	(0.47)	(0.47)
PTV _{59.4}	D _{98%}	96.94	96.65	96.00	97.32	97.05	96.41	97.39	97.21	96.66
		(6.71)	(6.60)	(6.27)	(6.86)	(6.78)	(6.45)	(6.94)	(6.83)	(6.57)
	D _{50%}	104.42	104.27	103.84	104.78	104.56	104.12	105.60	105.37	104.89
		(3.20)	(3.17)	(3.09)	(3.28)	(3.25)	(3.16)	(3.45)	(3.43)	(3.35)
PTV ₅₄	D _{98%}	100.01	99.66	98.85	100.41	100.15	99.40	100.37	99.69	99.62
		(1.47)	(1.50)	(1.54)	(1.39)	(1.60)	(1.63)	(1.53)	(2.46)	(1.60)
	D _{50%}	100.50	100.28	99.88	100.46	100.51	100.10	100.91	100.77	100.28
		(0.45)	(0.45)	(0.43)	(1.07)	(0.41)	(0.40)	(0.47)	(0.46)	(0.62)
	D _{98%}	101.83	101.50	100.66	102.45	102.14	101.30	102.36	102.20	101.65
		(0.78)	(1.11)	(1.15)	(1.34)	(1.31)	(1.32)	(0.92)	(0.99)	(1.09)
FOV 650 mm										
Opt resolution (mm)		1.27	1.27	1.27	2.54	2.54	2.54	5.08	5.08	5.08
Cal resolution (mm)		1.27	2.54	5.08	1.27	2.54	5.08	1.27	2.54	5.08
PTV ₇₀	D _{2%}	97.18	96.73	96.12	97.47	96.98	96.33	98.14	97.63	96.90
		(0.71)	(0.73)	(0.73)	(0.70)	(0.73)	(0.74)	(0.70)	(0.65)	(0.76)
	D _{50%}	100.67	100.47	99.98	101.07	100.88	100.38	101.31	101.10	100.65
		(0.44)	(0.39)	(0.39)	(0.41)	(0.42)	(0.40)	(0.42)	(0.40)	(0.39)
PTV _{59.4}	D _{98%}	98.17	97.82	96.81	98.72	98.39	97.44	98.72	98.47	97.78
		(4.77)	(4.70)	(4.59)	(4.79)	(4.71)	(4.60)	(4.90)	(4.85)	(4.75)
	D _{50%}	105.71	105.43	104.89	106.06	105.78	105.24	106.88	106.58	106.03
		(4.77)	(4.69)	(4.48)	(4.96)	(4.88)	(4.65)	(4.99)	(4.88)	(4.75)
PTV ₅₄	D _{98%}	100.27	99.93	98.92	101.01	100.73	99.73	100.72	100.53	99.83
		(1.25)	(1.34)	(1.45)	(1.14)	(1.25)	(1.39)	(1.23)	(1.32)	(1.49)
	D _{50%}	100.23	99.99	99.52	100.54	100.33	99.85	100.77	100.57	100.12
		(0.56)	(0.57)	(0.55)	(0.50)	(0.48)	(0.46)	(0.60)	(0.60)	(0.58)
	D _{98%}	101.42	101.07	99.95	102.40	102.06	100.88	102.11	101.93	101.21
		(1.09)	(1.15)	(1.19)	(1.01)	(1.04)	(1.01)	(0.96)	(1.07)	(1.13)

Opt, optimization; Cal, calculation; H, high resolution; M, medium resolution; L, low resolution; PTV, planning target volume and D_{x%}, dose at x% volume

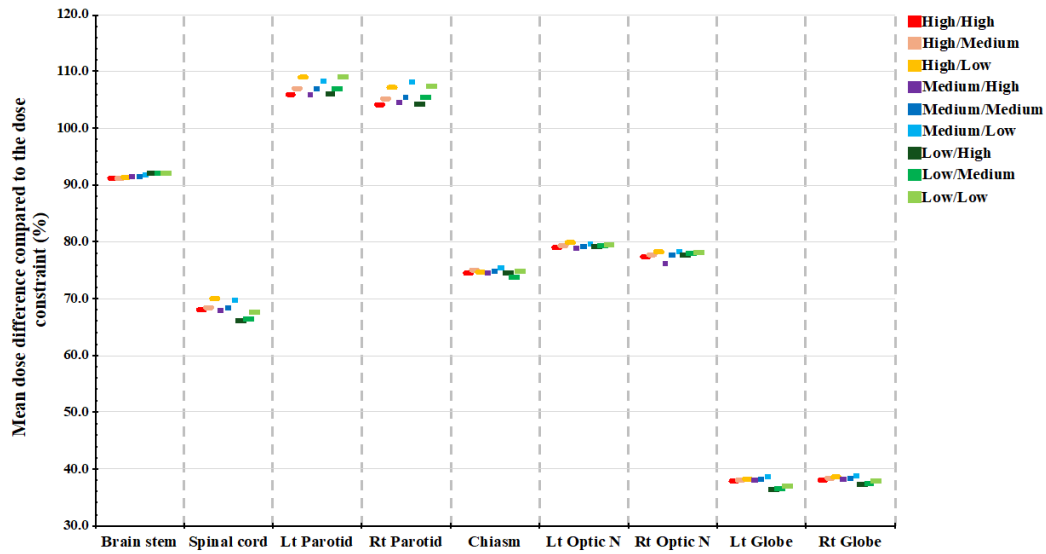


Figure 3. Comparison of percentage dose differences with dose constraint of organs at risk and dosimetric parameters in various resolutions of optimization and dose calculation.

Table 8. Statistical analysis (*p*-value) of target dosimetric parameters in various FOV

Target	Parameter	Optimization/calculation resolution scenario (%)								
		H/H	H/M	H/L	M/H	M/M	M/L	L/H	L/M	L/L
FOV 500 mm vs FOV 550 mm (p-value)										
PTV ₇₀	D _{2%}	-	-	-	-	-	-	-	-	-
	D _{50%}	-	-	-	-	-	-	-	-	-
	D _{98%}	-	-	-	-	-	-	-	-	-
PTV _{59.4}	D _{50%}	-	-	-	-	-	-	-	-	-
	D _{98%}	-	-	-	-	-	-	-	-	-
PTV ₅₄	D _{50%}	-	-	-	-	-	0.044	-	-	-
	D _{98%}	-	-	-	-	-	-	-	-	-
FOV 550 mm vs FOV 650 mm (p-value)										
PTV ₇₀	D _{2%}	0.026	-	-	0.009	0.033	-	0.023	-	-
	D _{50%}	-	-	-	-	-	-	-	-	-
	D _{98%}	-	-	-	-	-	-	-	-	-
PTV _{59.4}	D _{50%}	-	-	-	-	-	-	-	-	-
	D _{98%}	-	-	-	-	-	-	-	-	-
PTV ₅₄	D _{50%}	-	-	0.048	-	-	-	-	-	-
	D _{98%}	-	-	-	-	-	-	-	-	-
FOV 500 mm vs FOV 650 mm (p-value)										
PTV ₇₀	D _{2%}	-	-	-	-	-	-	-	-	-
	D _{50%}	-	-	-	-	-	-	-	-	-
	D _{98%}	-	-	-	-	-	-	-	-	-
PTV _{59.4}	D _{50%}	-	-	-	-	-	-	-	-	-
	D _{98%}	-	-	-	-	-	-	-	-	-
PTV ₅₄	D _{50%}	-	-	0.036	0.049	0.03	0.024	-	-	-
	D _{98%}	-	0.037	0.024	-	-	-	-	-	-

FOV, field of view; H, high resolution; M, medium resolution; L, low resolution; PTV, planning target volume and Dx%, dose at x% volume.

p-value was expressed only the data that had *p*-value less than 0.05

elements contained in each structure volume, particularly around the boundary of the structure. The elements at the object boundary are taken into account differently in the structures, depending on each TPS. In the optimization process of VOLO™ Ultra, a whole voxel was included in the PTVs if its partial volume was involved (15). Additionally, an accelerated optimization method was used to decrease the planning time. This method employed a lower resolution level in the optimization step (15). However, this down sampling was used only on the first or second optimization round (15). The enlargement of the target could be observed in this process and was dependent on the chosen resolution. The voxel of the optimization increased the size of the target volume when the low resolution was selected. This impact can be observed in Figure 1. However, the results found differences in the PTV_{59.4} and PTV_{54.0} at the level D_{98%}. These results showed the radiation dose was reduced when a low resolution of optimization was used. As the IMRT technique was employed in this study, the concept of target enlargement also applied across all targets, i.e., PTV_{70.0}, PTV_{59.4} and PTV_{54.0}. Although all targets were enlarged, the PTV_{59.4} and PTV_{54.0} lost a number of voxels due to the overlap and the adjacent region between each target, respectively.

The results demonstrated that there was a significant difference in almost all resolution scenarios when compared to the highest resolution. These differences were within 2.5%, which would indicate no significant difference in clinics. However, the coverage of PTV_{70.0} (D_{98%}) was found to be under 100% in all scenarios. This illustrates that the PTV_{70.0} receives a lower dose than the constraints due to the partial adjacency of the brainstem. This demonstrates that the enlargement of the PTVs might have less impact on the adjacent normal organ as shown by the dose values on brainstems in Figure 3. Although the TPS calculated the dose using a similar dose constraint, the performance of M/H, M/M, L/H and L/M scenarios showed a higher dose coverage than the H/H scenario. As part of the H/H scenario, these might be candidates of interest.

With regard to conformity, the results showed that the CI_{ICRU} value was similar in pattern to the PTV_{70.0}. The volume of a radiation dose is the numerator in this formula. These calculations con-

firm the assumption that the PTVs are enlarged by the increasing CI_{ICRU} value when the resolution of the optimization is decreased. The dose calculation resolution demonstrated that the volume of radiation was rapidly decreased by decreasing the resolution. By the binary numeric based calculation, the voxel of deposited dose would be enlarged by 2n as well. Although the concept of optimization might differ between each TPS, this tendency of the dose calculation resolution also confirms the work of Srivastava et al. (10), Kim et al. (6) and Chow et al. (16). In contrast, this was not observed in the HI value. As the formula for HI focused on the dose level, this study found a similar level of value in all resolution scenarios. However, this also revealed that all resolution scenarios would provide a similar dose range between D_{98%} and D_{2%} dose levels. In Figure 2a, the CI_{ICRU} value of a low optimization resolution presented with the highest value. This might indicate a limitation of using this resolution in the optimization step.

On the OARs, similar dose levels were also observed among some resolution scenarios. Similar dose levels were found on the brainstem, optic chiasm, both optic nerves and both globes. In the craniocaudal direction, an axial fan beam of the tomotherapy might involve a less inferior volume to these organs. This could be a reason that these organs were less impacted by various resolution scenarios. This is in contrast with the work of Srivastava et al. (10) that investigated using the C-arm based linear accelerator. The impact may increase with the size of the MLC. In our study, two other organs impacted by the various resolution scenarios were the spinal cord and both parotids. This result also confirms the work of Srivastava et al. (10). These three structures are located close to all PTVs. The increase in PTVs voxels must impact the volume of these structures. However, all OARs met the acceptance criteria, with the exception of both parotids. Due to the overlapping structures of the PTVs, the parotids might not have been kept within the criteria of the study, but this could be acceptable in clinics. Although all organs met the criteria, with the exception of both parotid glands, no significant differences were found regarding the resolution between the H/H and M/H scenarios. This scenario might represent an interesting resolution in clinical practice.

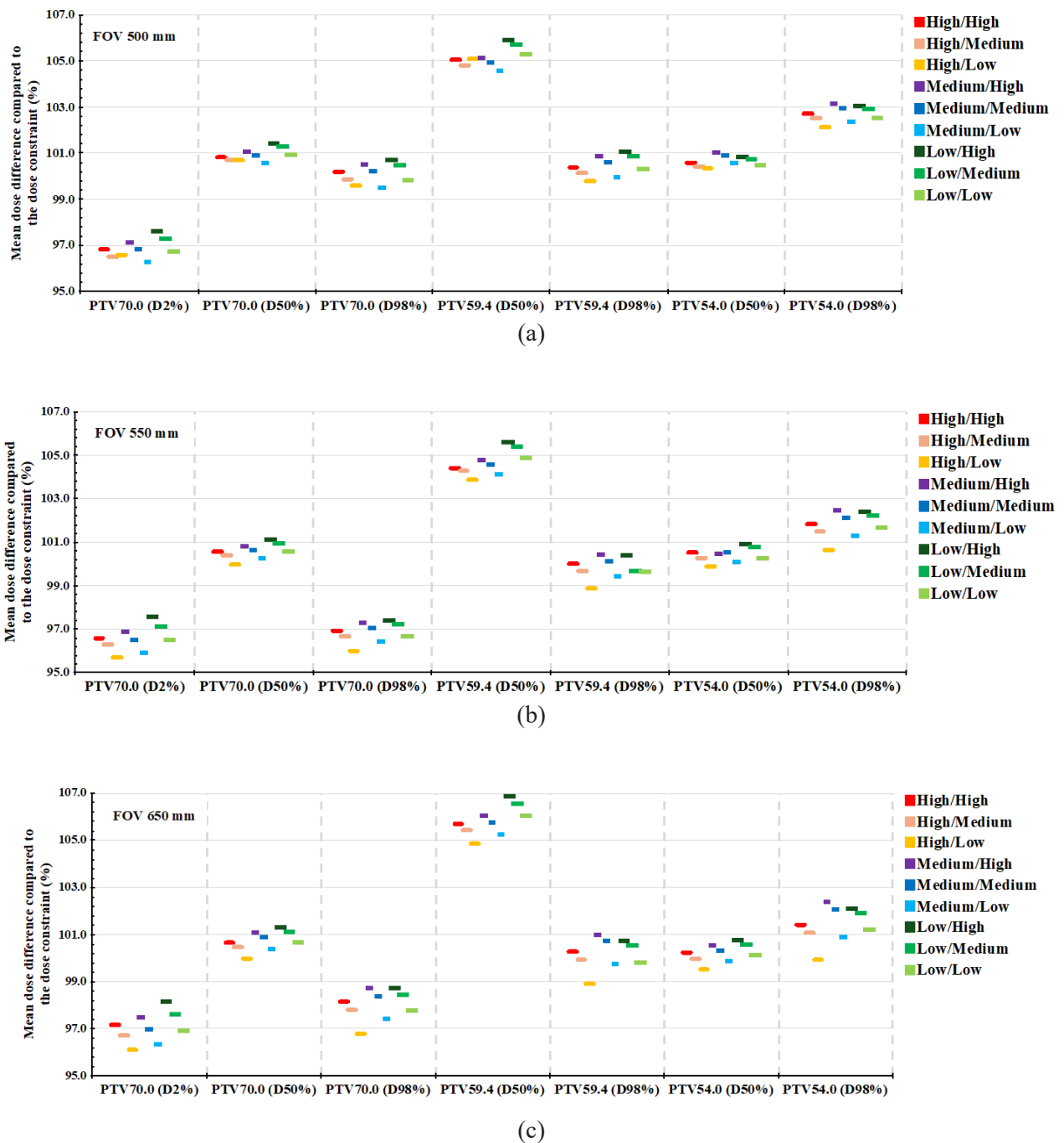


Figure 4. Mean percentage dose difference compared to dose constraint of PTVs dosimetric parameters in various resolutions of optimization and dose calculation and field of view (FOV). (a) Mean dosimetric parameters in FOV500 mm, (b) Mean dosimetric parameters in FOV550 mm and (c) Mean dosimetric parameters in FOV650 mm.

Treatment planning time

Regarding treatment planning time, other publications (5–7, 12) report that the most time-consuming practice was with the highest resolution. The present study found similar results. The treatment planning time would be higher for the optimization process than for the dose calculation process. Anchoring the optimization time,

the treatment planning time was average regards the optimization group. This showed that the planning time would decrease from high resolution to low resolution by the steps of the binary numeric base which were 347.89 sec ($\sim 2^8$ sec), 131.38 sec ($\sim 2^7$ sec) and 91.16 sec ($\sim 2^6$ sec) for high, medium and low resolution, respectively.

Table 9. Summary of the target and organs at risk dose impact using various optimization and dose calculation grid resolution.

Grid resolution		PTVs dose			OARs dose*	
Optimization	Calculation	PTV _{70.0}	PTV _{59.4}	PTV _{54.0}	Spinal cord	Parotids
Increase	Fixed		Decrease		No difference	
Decrease	Fixed		Increase		No difference	
Fixed	Increase		Increase		Decrease	
Fixed	Decrease		Decrease		Increase	

*Dose on other OARs were not dependent on various resolution both the optimization and dose calculation

Dosimetric parameters by various FOV

The FOV was one of the factors investigated in this study. In most scenarios, no significant differences were observed among the dosimetric PTVs parameters. Although the resolution of optimization and dose calculation were dependent on the FOV, the difference in the voxel size did not exceed 2.54 mm when the high and medium resolutions were applied. For these ranges of the FOV, the low-resolution level is not recommended.

The influence of optimization and dose calculation resolution on the targets and OARs dose is summarized in Table 9. The highest resolution of the optimization and dose calculation are recommended for the treatment planning. This resolution requires a longer planning time for generating the treatment plan. However, that may not impact centers that have a smaller number of patients. In many treatment centers the lower resolution can reduce the treatment planning time while maintaining optimal quality. Although the VOLO™ Ultra is a new technology in tomotherapy treatment planning and has an algorithm of accelerated optimization, the resolution can be selected for the optimization and dose calculation process. The selection of the lower resolution (medium resolution) can provide a shorter treatment planning time while retaining a plan quality equal to the highest resolution.

This study observed the impact of optimization and dose calculation resolution in the VOLO™ Ultra only for the high to low resolution. In this TPS, a very low resolution can be selected, a resolution that was not included in this study. This might be a limitation of this investigation. On the other hand, the accelerated optimization method was integrated in this program but not on the classic Precision® which might be an area of interest in future research.

CONCLUSIONS

This study investigated the impact on plan quality of using various resolutions of optimization and dose calculation. The results show that the resolution of M/H and M/M are of particular interest. These scenarios provide a higher dose coverage, have a mild impact on OARs and a moderate impact on conformity. The most beneficial of these scenarios can reduce the treatment planning time by 37.8% without a modification in the dose constraint. In this study, the plan quality was found to have had no impact with various FOVs of the CT image.

ACKNOWLEDGMENTS

This article has no acknowledgments.

FUNDING

This article has no support or funding.

CONFLICTS OF INTEREST

The authors have no conflicts of interest to report.

ADDITIONAL INFORMATION

Author contributions

S.T.: conceptualization, data curation, investigation, formal analysis, writing – original draft, writing – review and editing; A.W.: conceptualization, formal analysis, writing – review and editing, supervision; W.N.: formal analysis, writing – review and editing; S.W.: formal analysis, writing – review and editing; W.T.: formal analysis.

REFERENCES

1. De Felice F, Cattaneo C, Franco P. Radiotherapy and Systemic Therapies: Focus on Head and Neck Cancer. *Cancers (Basel)*. 2023;15:4232. PubMed PMID: 37686508

2. Taylor A, Powell M. Intensity-modulated radiotherapy--what is it? *Cancer Imaging*. 2004;4:68-73.
3. Chui C, Spirou S. Inverse planning algorithms for external beam radiation therapy. *Med Dosim*. 2001;26:189-97.
4. Rong Y, Welsh J. Dosimetric and clinical review of helical tomotherapy. *Expert Rev Anticancer Ther*. 2011;11:309-20.
5. Kawashima M, Kawamura H, Onishi M, Takakusagi Y, Okonogi N, Okazaki A, et al. The impact of the grid size on tomotherapy for prostate cancer. *J Med Phys*. 2017;42:144-50.
6. Kim K, Chung J, Suh T, Kang S, Kang S, Eom K, et al. Dosimetric and radiobiological comparison in different dose calculation grid sizes between Acuros XB and anisotropic analytical algorithm for prostate VMAT. *PLoS One*. 2018;13:e0207232. PubMed PMID: 30419058
7. Park J, Kim S, Park H, Lee J, Kim Y, Suh T. 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. *Radiat Oncol*. 2014;9:5. PubMed PMID: 24387278
8. Snyder Karen C, Liu M, Zhao B, Huang Y, Ning W, Chetty I, et al. Investigating the dosimetric effects of grid size on dose calculation accuracy using volumetric modulated arc therapy in spine stereotactic radiosurgery. *J Radiosurg SBRT*. 2017;4:303-13.
9. Spirou S, Fournier-Bidoz N, Yang J, Chui C, Ling C. Smoothing intensity-modulated beam profiles to improve the efficiency of delivery. *Med Phys*. 2001;28:2105-12.
10. Srivastava S, Cheng C, Das I. The dosimetric and radiobiological impact of calculation grid size on head and neck IMRT. *Pract Radiat Oncol*. 2017;7:209-17.
11. Yawichai K, Chitapanarux I, Wanwilairat S. Helical tomotherapy optimized planning parameters for nasopharyngeal cancer. *Journal of Physics: Conference Series*. 2016;694:012002.
12. Park J, Park S, Kim J, Carlson J, Kim J. The influence of the dose calculation resolution of VMAT plans on the calculated dose for eye lens and optic pathway. *Australas Phys Eng Sci Med*. 2017;40:209-17.
13. International Commission on Radiation Units and Measurements. *J ICRU*. 2014;14:Np.
14. Oelfke U, Bortfeld T. Inverse planning for photon and proton beams. *Med Dosim*. 2001;26:113-24.
15. Incorporated. A. Radixact Physics Essential Course Workbook 1058101.K2022.
16. Chow J, Jiang R. Dose-volume and radiobiological dependence on the calculation grid size in prostate VMAT planning. *Med Dosim*. 2018;43:383-9.