Dosimetric evaluation of three commercial radiotherapy planning systems for lung cancer and nasopharyngeal carcinoma cases

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Research

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Abstract

Purpose: To identify planning systems and techniques suitable for different sites tumors by analyzing dosimetric differences using three commercial radiotherapy planning systems: Tomotherapy, Monaco and Eclipse.

Methods: We retrospectively analyzed 20 lung cancer and 8 nasopharyngeal carcinoma (NPC), and each patient plans were designed using the three systems. The dose distribution of the target and organs at risk (OARs) were compared, and monitor unit (MU) and treatment time were also evaluated.

Results: For lung cancer, mean dose of PGTV, PTV1 and PTV2 in Monaco and Tomo plans were lower than Eclipse plan. PTV2 CI in Monaco and Eclipse plans were better than Tomo plans (p=0.002, p=0.022). Monaco and Tomo plans were better than Eclipse plan regarding to mean dose and V_{15Gy} of lungs; the lowest lungs V_{20Gy} and V_{30Gy} were provided by Tomo plan. The esophagus, heart and SpinalCord_03 dose were lowest in Monaco plan, and the maximum dose and V_{45Gy} of SpinalCord_03 were 592.1cGy and 1.37% lower than Eclipse plan, respectively. For NPC, mean dose of PGTV, PTV1 and PTV2 in Eclipse plan were superior to Tomo plan (p=0.008, p=0.000, p=0.003); PTV2 $V_{95\%}$ in Tomo plan was increased by 1.64% than Eclipse plan. There was no significant difference between Monaco and Eclipse plans. Tomo plan showed better spinal cord and brainstem protection, with spinal cord max dose 249.38cGy lower than Eclipse plan and 555cGy lower than Monaco plan, respectively.

Conclusion: Although the three plans reflected their respective advantages in different aspects, in general, the Monaco plan (VMAT) was the best choice for lung cancer, and for the more advanced nasopharyngeal carcinoma, the Tomo plan (HT) was superior to the other two plans.

1. Introduction

Mortality due to cancer is gradually increasing. An analysis of death causes in 195 countries from 1980 to 2017 showed that cancers accounted for 23.3% of non-communicable disease-related deaths, with the largest number of deaths caused by tracheal carcinoma, bronchogenic carcinoma, and lung cancer (188 million people) [1].Morbidity and mortality analysis of 36 cancers in 185 countries revealed that the highest cancer mortality rate was attributable to lung cancer, accounting for 18.4% of total cancer deaths [2]. The regional distribution of nasopharyngeal carcinoma (NPC) is very obvious. According to data from international research institutions, 70% of new nasopharyngeal cancer patients (127,000) in 2018 occurred in East and Southeast Asia [3].

Radiation therapy is an effective treatment for lung cancer and NPC. Intensity-modulated radiation therapy (IMRT) is an important technique to improve target coverage and reduce the dose of organs at risk (OARs) [4]. Based on IMRT, new technologies have been developed: volumetric modulated arc therapy (VMAT) and helical tomotherapy (HT). Kannarunimitet al. identified that RapidArc, SmartArc and Tomo (HT) provided more effective treatment than IMRT in lung cancer [9]. RapidArc and SmartArc had the

lowest mean dose and the lowest V_{20Gy} of lung, but there was no significant difference between RapidArc and SmartArc. Some studies found RapidArc plans had better lungs sparing, compared to HT and IMRT [10~12].For head and neck cancers, many studies showed that the VMAT and HT afford better target dose uniformity and coverage than IMRT, however, HT had better OARs sparing than VMAT, such as brainstem and spinal cord[5~8,13~17]. In other studies, the difference between IMRT and VMAT in plan quality found that the difference was not significant. The obvious advantage of VMAT was that it reduced the treatment time. Because OARs were always in the beam path of VMAT during the rotation, IMRT was better than VMAT for the small organs closing to tumors, such as optical nerve or lens.[18~21].The purpose of this study was to compare the dosimetric differences of treatment planning in Tomotherapy, Monaco, and Eclipse for lung cancer and NPC.

2. Materials And Methods

2.1. Patient characteristics

We retrospectively analyzed 28 patients (19 men and 9 women) admitted to the Sun Yat-sen University Cancer Center from 2015 to 2018, with median age of 58.5 years. There were 20 cases of lung cancer and 8 cases of NPC. Patient characteristics are presented in Table 1. All patient data have been anonymized.

Patient No.	Age(year)	Sex	Stage	Patient No.	Age(year)	Sex	Stage
Lung cancer				NPC			
1	76	M	T3N2M0	21	34	M	T3N2M0
2	75	M	T2aN1M0	22	53	M	T2N0M0
3	59	M	T4N3M0	23	47	F	T3N3M0
4	63	M	T1aN2M0	24	46	F	T3N1M0
5	63	M	T2N2M0	25	43	M	T3N2M0
6	65	F	T2N1M0	26	40	M	T4N2M0
7	57	M	T4N2M0	27	35	M	T4N2M0
8	70	F	T1aN2M0	28	38	F	T3N1M0
9	69	M	T3N2M0				
10	61	F	T4N3M0				
11	61	M	T1N3M0				
12	68	M	T4N2M0				
13	58	M	T4N2M1				
14	61	M	T3N2M0				
15	44	M	T4N3M0				

Patient No.	Age(year)	Sex	Stage	Patient No.	Age(year)	Sex	Stage
16	63	F	T4N3M0				
17	58	F	T2bN2M0				
18	49	F	T2aN2M0				
19	67	M	T4N3M0				
20	54	M	TxN2M0				

Table 1
Patient characteristics (F: female; M: male)

2.2. Contouring

Both targets and OARs delineation in all cases was performed in Monaco (Version 5.11.1) treatment planning system (TPS). Patients with lung cancer were fixed by vacuum bag with hands raised up. Head-neck-shoulder fixation masks were used for patients with NPC. All patients were scanned in the supine position on a Big Bore CT scanner (Brilliance™ CT, Philips, The Netherlands).Patients with lung cancer were treated with 4D CT after their breathing stabilized, the slice thickness was 5 mm. All NPC patients were scanned with a slice thickness of 3 mm.

2.2.1. Lung cancer GTV: the primary tumors and positive lymph nodes. CTV: GTV expansion of 6 mm and involved lymph node areas, CTV1 contained a high-risk lymph node drainage area, and CTV2 contained a low-risk drainage area and supraclavicular drainage area). PTV: GTV/CTV expansion of 5 ~ 10 mm in all direction [22].

2.2.2. NPC GTVnx: Tumors visualized by imaging and physical examination included posterior pharyngeal lymph nodes. GTVn_L/R: Imaging and physical examination for the diagnosis of metastatic lymph nodes. CTV1: GTVnx expansion of 5 ~ 10 mm, including all mucosa. CTV2: GTVnx expansion of 10 ~ 20 mm, common invasive area, invasion prevention drainage area for the next station lymph node. More details could be found in RTOG 0615 and studies of Grégoire and Lee [23~24]. The corresponding PTV was externally expanded by 3 mm in the three-dimensional direction of GTVnx, CTV1, and CTV2, and was automatically generated by the planning system.

2.3. Treatment planning

2.3.1. Eclipse plan The Eclipse (Version 11.0, Varian Medical Systems, Palo Alto, CA, USA) treatment planning system was used for the RapidArc plans (single arc) for lung cancer and the IMRT plan(9F) for NPC. All plans were based on a Trilogy linear accelerator with 120 Millennium™ MLCs and a blade width of 5 mm, calculated with 6 MV energy, and the dose calculation algorithm was an anisotropic analytical algorithm (AAA).

2.3.2. Monaco plan The Monaco (Version 5.11.01, Elekta Medical Systems, Sweden) planning system was used for the VMAT plans (single arc) for lung cancer and the IMRT plan(9F) for NPC. All plans were based on a Versa HD linear accelerator with 160 Agility MLCs and a 5 mm blade width. The energy was 6 MV and the Monte Carlo algorithm was used for dose calculation.

2.3.3. Tomotherapy plan (Tomo plan) Hi.Art (Version 5.1.1, Tomotherapy Inc., Madison, WI, USA) was used for the helical tomotherapy plan for lung cancer and NPC with the following parameters: A field with 2.5 cm width, a modulation factor of 3.8 and a pitch of 0.287. The superposition/convolution algorithm was used for dose calculation. All treatment plans were designed with an energy of 6 MV.
Single-arc VMAT (181°~179°) was used for lung cancer in both the Eclipse and Monaco planning systems. The grid spacing was set to 0.3 cm. The prescribed dose was 6500 cGy, i.e., 250 cGy per time for 26 fractions. And For NPC cases, both Eclipse and Monaco systems used the nine-field IMRT (160°, 120°, 80°, 40°, 0°, 320°, 280°, 240°, 200°). The prescribed dose was 7008 ~ 7020 cGy, 219 ~ 234 cGy each time, 30 ~ 32 fractions. Table 2 was constraints of the targets and OARs, and all plans met the clinical requirement in our center.

OARs & Target		Parameters		D_{Max}
	PTV (Lung cancer)	$V95_{\%}$>95% prescribed dose		110% prescribed dose
lung	Lungs	$V_{20Gy} < 35\%$		
cancer	Spinal cord03			46 Gy
	Esophagus	$V_{50Gy} < 15\%$		63 Gy
	Heart	D_{mean}<35Gy $V_{40Gy} < 60\%$		
	PTV(NPC)	$V_{100\%}$>95% prescribed dose	110% prescribed dose	
	Brainstem		60 Gy	
	Spinal cord		50 Gy	
NPC	Parotid glands	$V_{30Gy} < 50\%$		
	Optical Nerve_L/R		60 Gy	
	Optical Chiasm		54 Gy	
	Len_L/R		8 Gy	
	TemporalLobe_L/R	$V_{60Gy} < 2\%$		

Table.2

Dose requirements for targets and OARs

2.4. Plan evaluation

All treatment plans dose was normalized: Target coverage of the Eclipse plan and Monaco plan was normalized to dose coverage of the corresponding target area of the Tomo plan. All the dosimetric parameters were obtained from the dose volume histogram (DVH), with resolution of 0.1 cm and the bin size of 1 cGy.

To assess the dose distribution, Homogeneity index (HI) and conformity index (CI) were used. The calculation formulas were as follows: (see Equations 1 and 2 in the Supplementary Files)

$D_{2\%}$ is the minimum absorbed dose covering 2% of the target volume, and $D_{98\%}$ is the minimum absorbed dose covering 98% of the target volume. $V_{Target95\%}$ is the target volume covered by 95% of prescription, V_{Target} is target volume, and $V_{body95\%}$ is volume covered by 95% prescription. The closer CI value to 1 means better conformity of the plans, and the lower HI value means better homogeneity of radiation distribution.
Finally, this study also compares the cumulative monitoring unit (MU) and treatment time of different plans.

2.5 Statistical analysis

All the data was analyzed with SPSS 25.0 (SPSS Inc., Chicago, IL, USA). And the analysis of variance was performed on the data that accorded with the normal distribution and the homogeneity of the variance, and the least-significant difference test (LSD-t) was also performed. For data that did not meet the normality test, the Friedman rank-sum test was selected and Bonferroni correction was performed for the test results. The difference was considered statistically significant at $p < 0.05$. (In SPSS, if $p > 0.05$ in the Friedman test, then the three distributions are considered to be no different and no multiple comparative analysis is performed).

3. Results

3.1 Lung cancer cases

3.1.1 Targets

Table 3
Comparison of dosimetric parameters for lung cancer

	Eclipse plan(E)	Monaco plan(M)	Tomo plan(T)	P value		
PGTV				E&M	M&T	E&T
$D_{1\%}$ (cGy)	7236.90 ± 145.14	7036.76 ± 127.97	7017.66 ± 172.53	0.000*	0.688	0.000*
$D_{50\%}$ (cGy)	6960.23 ± 118.98	6800.280 ± 113.58	6818.69 ± 145.63	0.000*	1.000	0.001*
$D_{95\%}$ (cGy)	6394.02 ± 118.96	6363.570 ± 156.24	6393.807 ± 154.21	0.507	0.510	0.996
$V_{95\%}$ (%)	98.00 ± 1.48	97.41 ± 1.99	97.80 ± 1.83		0.086	
$V_{100\%}$ (%)	92.12 ± 3.03	92.09 ± 3.09	92.12 ± 3.09	0.976	0.970	0.995
$V_{105\%}$ (%)	68.24 ± 11.38	37.96 ± 26.68	42.60 ± 29.04	0.001*	1.000	0.008*
Max Dose	7396.37 ± 176.63	7222.70 ± 147.12	7113.45 ± 201.89	0.003*	0.055	0.000*
Mean Dose	6893.52 ± 109.82	6759.05 ± 109.65	6766.90 ± 129.81	0.000*	1.000	0.000*
HI	0.15 ± 0.03	0.14 ± 0.04	0.13 ± 0.05	0.295	0.611	0.122
CI	0.49 ± 0.12	0.50 ± 0.10	0.54 ± 0.12	1.000	0.022*	0.034*
PTV1						
$D_{1\%}$ (cGy)	7212.84 ± 152.22	7015.11 ± 130.72	6995.39 ± 175.36	0.000*	0.687	0.000*
$D_{50\%}$ (cGy)	6784.99 ± 167.76	6696.97 ± 142.02	6659.54 ± 147.94	0.008*	0.342	0.000*
$D_{95\%}$ (cGy)	5813.93 ± 197.44	5953.71 ± 105.61	5823.05 ± 188.60	0.001*	0.008*	1.000
$V_{95\%}$ (%)	96.00 ± 3.16	97.74 ± 1.28	96.56 ± 1.80	0.003*	0.013*	1.000
$V_{100\%}$ (%)	91.13 ± 5.97	94.09 ± 2.38	91.67 ± 3.05	0.000*	0.003*	1.000
$V_{105\%}$ (%)	81.52 ± 10.21	83.98 ± 8.39	77.43 ± 14.55	0.618	0.034*	0.618
Max Dose	7405.92 ± 186.33	7222.70 ± 147.12	7110.05 ± 205.41	0.002*	0.054	0.000*

Values are shown as mean ± SD. *Significant at $p < 0.05$.

	Eclipse plan(E)	Monaco plan(M)	Tomo plan(T)		P value	
Mean Dose	6668.05 ± 157.16	6602.76 ± 124.26	6549.83 ± 136.48	0.022*	0.246	0.000*
HI	0.23 ± 0.03	0.20 ± 0.03	0.22 ± 0.05	0.000*	0.054	0.057
CI	0.67 ± 0.08	0.72 ± 0.06	0.71 ± 0.13	0.246	1.000	0.034*
PTV2						
$D_{1\%}$ (cGy)	7189.57 ± 151.50	6993.53 ± 132.25	6977.26 ± 170.89	0.000*	0.737	0.000*
$D_{50\%}$ (cGy)	6281.03 ± 391.99	6201.09 ± 536.64	6099.39 ± 509.63	1.000	0.000*	0.000*
$D_{95\%}$ (cGy)	4769.77 ± 147.87	4557.40 ± 159.69	4589.71 ± 132.82	0.000*	0.490	0.000*
$V_{95\%}$ (%)	99.11 ± 0.65	97.53 ± 1.31	97.97 ± 1.24	0.005*	1.000	0.008*
$V_{100\%}$ (%)	97.82 ± 1.45	95.18 ± 2.31	96.31 ± 1.68	0.002*	1.000	0.005*
$V_{105\%}$ (%)	95.14 ± 2.99	90.40 ± 5.56	87.42 ± 13.68	0.013*	1.000	0.003*
Max Dose	7410.74 ± 176.11	7222.70 ± 147.12	7109.40 ± 201.04	0.001*	0.047*	0.000*
Mean Dose	6131.76 ± 264.72	6011.17 ± 320.46	5931.31 ± 298.55	0.005*	0.081	0.000*
HI	0.42 ± 0.04	0.47 ± 0.05	0.44 ± 0.06	0.522		
CI	0.57 ± 0.09	0.58 ± 0.06	0.50 ± 0.07	1.000	0.002*	0.022*
Values are shown as mean ± SD. *Significant at $p < 0.05$.						

PTVs dosimetric parameters and comparisons among the three plans were showed in Table 3. There was no significant difference in PGTV coverage ($D_{95\%}$, $V_{95\%}$, $V_{100\%}$) among the three plans (all $p > 0.05$). PTV1 of Monaco plan was obviously better than the other two plans, and PTV2 coverage in Eclipse plan significantly better than Monaco and Tomo plans yet. The high-dose in the Monaco and Tomo plans ($D_{1\%}$, $V_{105\%}$, maximum dose) was lower than that in the Eclipse plan ($p < 0.01$) for PGTV. The $D_{1\%}$, maximum dose, mean dose of PTV1 and $D_{1\%}$, $V_{105\%}$ and mean dose of PTV2 in the Monaco and Tomo plans were less than the Eclipse plan ($p < 0.05$).

CI of Tomo plan significantly was superior to Eclipse or Monaco plans for PGTV, and Tomo plans provided higher CI for PTV1 than the Eclipse plans ($p = 0.034$). The Monaco plan showed better conformation than the Tomo plan for PTV2($p = 0.002$). The HI of Monaco plan was lower than that of

Eclipse plan for PTV1($p < 0.01$) .The mean dose of PTVs in Tomo and Monaco plan were significantly lower than Eclipse plan.(all $p < 0.05$).

In summary, Monaco plan (VMAT) and Eclipse plan (RapidArc) showed good target coverage and better CI, while HI of Monaco plan was better than those of the other two plans, the Tomo and Monaco plans showed good high-dose control for the lung cancer target.

3.1.2 OARs

The maximum dose and mean dose in Monaco plan of esophageal were significantly lower than the other two plans. 150.06 cGy and 411.31 cGy lower than Eclipse plan, respectively, and 103.65 cGy and 239.94 cGy lower than those in Tomo plan, respectively (all $p < 0.05$).Comparing to Eclipse plans, esophagus V_{50Gy} in Monaco and Tomo plans were reduced by 3.25% and 3.96%, respectively ($p < 0.01$), and there was no significant difference between the Monaco and Tomo plans ($p = 0.504$).

Tomo plan provided superior protection of lungs V_{20Gy} (28.77%) and mean dose(1807.05 cGy) in three plans. The lungs V_{15Gy} in the Monaco and Tomo plans were 4.73% and 3.72% lower than that in the Eclipse plan (47.29%), respectively ($p < 0.05$), There was no significant difference for mean dose and V15Gy for lungs between Monaco and Tomo plans. Lungs V_{30Gy} of Tomo plan was 3.36% less than Monaco plan, but lungs V_{10Gy} was 8.23% higher than Monaco plan ($p = 0.001, 0.017$).

The lung V_{10Gy} and V_{30Gy} in the Eclipse plan were not significantly different from those in the other two plans ($p > 0.05$). There were no significant differences in lung V_{5Gy} and V_{40Gy} among the three plans ($p > 0.05$).

Monaco plan showed good protection for heart and spinal cord. Comparing Tomo plan, V_{20Gy}, V_{30Gy} and V_{40Gy} of heart in the Monaco plan were reduced by 6.86%, 3.68% and 1.95% ($p < 0.05$), respectively. And there was no significant difference between the Eclipse and Monaco plans ($p = 1.00$). SpinalCord_03 maximum dose and V_{45Gy} in the Monaco plan (4308.35 cGy and 0.18%) were lower than those in the Eclipse plan (4900.45 cGy and 1.55%, $p < 0.01$), and the values in the Tomo plan were not significantly different from those in the other two plans (all $p > 0.05$).There was no significant difference among the three planning systems for Body_5 mm(body minus 5 mm expanded target) V_{5Gy}, V_{10Gy}, V_{20Gy} and V_{30Gy} ($p > 0.05$). DVHs for the esophagus, lungs, heart, and SpinalCord_03 are shown in Fig. 1. And the surplus parameters result was not statistically different among the three plans (all $p > 0.05$), as detailed in Other files Table 1.

Overall, Monaco (VMAT) plan offered better protection for more OARs from lung cancer. Of the three plans, the Tomo plan provided optimal V_{20Gy} and V_{30Gy} protection for the lungs, except for V_{10Gy}.Tomo plan provided the most MU and the longest treatment time for lung cancer cases. The average was 7383 MU, and the treatment time was 6 ~ 12 min. Eclipse plan (RapidArc) had the least MU (620 MU) and treatment time (2 ~ 3 min). Monaco plan (VMAT) the average MU of these plans was 1150 MU, and there was a fair treatment time with the eclipse plan.

3.2. NPC cases

3.2.1 Targets

Table 4
Comparison of dosimetric parameters for NPC

	Eclipse plan(E)	Monaco plan(M)	Tomo plan(T)	P value		
PGTV				E&M	M&T	E&T
$D_{1\%}$ (cGy)	7599.65 ± 62.50	7434.46 ± 127.36	7288.86 ± 55.31	0.001*	0.003*	0.000*
$D_{50\%}$ (cGy)	7311.99 ± 36.46	7224.4184.41	7170.84 ± 49.57	0.073	1.000	0.008*
$D_{95\%}$ (cGy)	7096.81 ± 21.62	7086.49 ± 53.28	6968.48 ± 31.26	0.401	0.073	0.001*
$V_{95\%}$ (%)	99.95 ± 0.10	99.89 ± 0.18	99.82 ± 0.40	0.055		
$V_{100\%}$ (%)	98.91 ± 0.24	98.51 ± 0.07	92.02 ± 2.90	0.137	0.137	0.000*
$V_{105\%}$ (%)	38.50 ± 11.41	14.10 ± 24.28	0.48 ± 0.96	0.240	0.240	0.001*
Max Dose	7763.06 ± 80.71	7647.50 ± 142.69	7388.00 ± 57.04	0.401	0.073	0.001*
Mean Dose	7309.30 ± 34.73	7223.21 ± 82.74	7146.65 ± 46.06	0.073	1.000	0.008*
HI	0.07 ± 0.01	0.05 ± 0.01	0.05 ± 0.01	0.000*	0.977	0.000*
CI	0.30 ± 0.10	0.32 ± 0.10	0.39 ± 0.12	0. 640	0.203	0.088
PTV1						
$D_{1\%}$ (cGy)	7571.40 ± 62.129	7406.73 ± 127.88	7275.52 ± 54.96	0.001*	0.007*	0.000*
$D_{50\%}$ (cGy)	7164.55 ± 72.99	7122.77 ± 101.47	6963.86 ± 86.17	0.351	0.002*	0.000*
$D_{95\%}$ (cGy)	6528.79 ± 160.30	6502.88 ± 186.05	6351.75 ± 175.74	0.769	0.098	0.055
$V_{95\%}$ (%)	99.92 ± 0.17	99.92 ± 0.13	99.93 ± 0.09	0.568		
$V_{100\%}$ (%)	99.51 ± 0.53	99.56 ± 0.40	99.15 ± 0.73	0.862	0.163	0.218
$V_{105\%}$ (%)	95.14 ± 2.49	94.05 ± 3.47	83.55 ± 6.45	0.952	0.037	0.001*
Max Dose	7772.80 ± 88.77	7643.25 ± 142.37	7388.00 ± 57.04	0.019*	0.000*	0.000*
Mean Dose	7097.08 ± 85.76	7033.10 ± 121.22	6888.99 ± 78.36	0.201	0.007*	0.000*
HI	0.16 ± 0.02	0.140 ± 0.02	0.14 ± 0.03	0.008*	1.000	0.073

	Eclipse plan(E)	Monaco plan(M)	Tomo plan(T)	P value		
CI	0.26 ± 0.07	0.29 ± 0.08	0.35 ± 0.10	0.572	0.171	0.061
PTV2						
$D_{1\%}$ (cGy)	7490.95 ± 66.29	7345.83 ± 127.84	7242.20 ± 51.30	0.004*	0.029*	0.000*
$D_{50\%}$ (cGy)	6456.56 ± 251.00	6407.68 ± 312.74	6244.65 ± 290.26	0.736	0.267	0.153
$D_{95\%}$ (cGy)	5674.60 ± 241.74	5708.73 ± 240.36	5718.64 ± 201.25	0.768	0.932	0.704
$V_{95\%}$ (%)	97.96 ± 1.15	98.48 ± 0.77	99.60 ± 0.22	0.401	0.073	0.001*
$V_{100\%}$ (%)	96.12 ± 1.44	96.71 ± 1.21	98.15 ± 0.92	0.336	0.027*	0.003*
$V_{105\%}$ (%)	88.69 ± 3.74	80.73 ± 9.71	70.36 ± 9.13	0.060	0.017*	0.000*
Max Dose	7775.44 ± 92.25	7609.88 ± 149.23	7388.00 ± 57.04	0.401	0.073	0.001*
Mean Dose	6482.09 ± 207.98	6424.89 ± 241.65	6312.20 ± 181.73	0.634	0.137	0.003*
HI	0.33 ± 0.06	0.30 ± 0.04	0.26 ± 0.04	0.240	0.240	0.001*
CI	0.75 ± 0.05	0.76 ± 0.06	0.77 ± 0.11	0.607		

Values are shown as mean ± SD. *Significant at $p < 0.05$

Target coverage ($D_{95\%}$, $V_{95\%}$ and $V_{100\%}$) for PGTV in Eclipse plan showed significant superior to Tomo plan, and Tomo plan had better coverage for PTV2. No significant difference was found in three plans of target coverage for PTV1 and PGTVnd_L/R. For mean dose of PTVs, Tomo plan was significantly lower than Eclipse plan. (all $p < 0.05$). PTV1 of Tomo plan was reduced by 144.11 cGy and 208.09 cGy than Eclipse plan and Monaco plan.

The high-dose control (maximum dose, $D_{1\%}$ and $V_{105\%}$) of Tomo plan for PTVs were superior to the other two plans. The PTV1 maximum dose in the Tomo plan was reduced by 384.80 cGy and 255.25 cGy compared to those in the Eclipse and Monaco plans (all $p < 0.05$). For PGTV and PTV2, the maximum dose of Tomo plan were significantly lower than Eclipse plan, and Monaco plan showed no significant difference with the other two plans. PGTVnd_L/R maximum dose in the Tomo plan were lower than those in the Eclipse plan.

Tomo plan had better homogeneous for targets than the other two plans. There was no significant difference for CI for PTVs in the three plans, except for PGTVnd_L.

In summary, the Tomo plan was superior to the IMRT in Eclipse and Monaco plans with respect to target coverage, target high-dose control, CI and HI of the NPC cases in our study. However, the Monaco plan was better than the Eclipse plan in $D_{1\%}$ control of the target (PGTV, PTV1, PTV2) and PGTV homogeneity. Details are shown in Table 4.

3.2.2 OARs

Brainstem and spinal cord dose of Tomo plan were significantly lower than those in the other two plans. In details, brainstem mean dose was 1117.39 cGy and 922.38 cGy lower than those in the Eclipse and Monaco plans, while maximum dose (5477.38 cGy) reduced by 249.38 cGy and 555 cGy, respectively ($p < 0.05$). The V_{65Gy} and V_{60Gy} of the PRV-BS in Tomo plan were 22.58%, 30.25% lower than those in the Eclipse plan, respectively. and 22.09% and 27.47% lower than Monaco plan (all $P < 0.05$) The mean dose of spinal cord and PRV-SC in the Tomo plan were 430.52 cGy and 368.33 cGy less than the Eclipse plan, and 637.08 cGy and 480.64 cGy lower than the Monaco plan.

Mean dose of OR Eye-R in the Tomo plan (3711.93 cGy) was lower than that in the Eclipse and Monaco plans (3742.29 cGy and 4705.50 cGy, $p < 0.05$).Compared to the Eclipse plan, the mean dose of OR Len-L/R in the Tomo plan was reduced by 496.72 cGy and 795.53 cGy, respectively. The PRV-O.N(L) mean doses in the Eclipse plan were 483.87 cGy and 623.48 cGy lower than those in the Monaco and Tomo plans, respectively, and PRV-O.N(R) V_{60Gy} decreased by 9.98% and 23.41%, respectively ($p < 0.05$).

The Pariod_R_Norm V_{35Gy} in the Eclipse plan was 14.68% lower than the Tomo plan ($p = 0.018$).

The body_5 mm V_{10Gy} for the Eclipse and Monaco plans were 10.5% and 8.2% lower than the Tomo plan, and body_5 mm V_{20Gy} in the Eclipse plan was 6.76% less than the Tomo plan ($p = 0.022$). The surplus parameters result was not statistically different among the three plans (all $p > 0.05$), as detailed in Other files Table 2.

All in all, the Tomo plan was superior to the Eclipse and Monaco IMRT plans in protecting OARs such as the brain stem, PRV-BS, spinal cord, and PRV-SC of NPC. And Eclipse IMRT plan had significant advantages in protecting small organs (such as optic nerve). DVHs of brain stem and PRV-BS, spinal cord and PRV-BS, OR Eye-L/R and PRV-O.N (L/R) were shown in Fig. 2.

NPC of the Tomo plan still had the most MU and longest treatment time, which were 9364MU and 8 ~ 13 min, respectively. Eclipse plan had less MU (1608MU) with shortest treatment time (4 ~ 6 min), and Monaco plan provided the least average MU(1226MU) and less treatment time(6 ~ 8 min).

4. Discussion

This study analyzed dosimetric differences in different disease types of three treatment planning systems, including the VMAT vs RapidArc, and IMRT of Monaco and Eclipse. In order to reduce the difference caused by objective factors, all the plans in our study were done by experienced physicist and approved by radiologists. And the technology is inclined to the clinical protocol of the center.

The results of this study indicated that the Tomo plan (HT) had good target high-dose control for lung cancer and NPC, which was proved by previous studies [5,13–16, 12]. In lung cancer case, the Tomo plan also reduced the normal lung dose in addition to affording the advantages of high-dose control in the

target. Studies have shown that the Tomo plan offered an advantage over lungs V_{20Gy} [10]. Our study found that Tomo plan still showed advantages over the other two plans with respect to lungs V_{30Gy}.The results obtained by Jacob et al. [12] have showed that the VMAT plan can improve the protection of normal tissues. The results in our study showed:VMAT plans and RapidArc plans provided good target coverage and better CI while the Monaco plan had better HI than the other two plans. Moreover, Monaco plan was better than the Eclipse plan for protecting most organs. It may be resulted from anisotropic analytical algorithm (AAA)in Eclipse plans, and some studies have shown that AAA may overestimate the dose of low-density tissues (such as lungs) [11, 25], and the Monte Carlo was advantageous for these organizations [26].

For NPC cases, the Tomo plan showed better dose distribution, target coverage, and protection of OARs for patients with T3, N2 and later stage cancer[5,13–16].At the same time, the results in this study proved that the Tomo plan provided good protection for most OARs in NPC, especially for the brainstem, PRV-BS, spinal cord, and PRV-SC. But the PRV-ON_L/R maximum dose of the Tomo plan was higher, which was consistent with the results reported by Szu-Huai Lu et al. [26].This study found that the Eclipse IMRT plan revealed a slight advantage in controlling doses to the Eye_L/R, PRV-O.C, PRV-O.N_L/R, and temporal lobe. Several studies have shown that the Tomo plan is advantageous for protection of the parotid gland [13, 16, 25]. However, in this study, there were basically no significant differences in the protection of the parotid gland in the three plans, which may be related to advanced and the larger target volume of the selected patients. As far as the three planning systems concerned, the Monaco plan (VMAT) provided the optimal plan for the lung cancer case, while Tomo (HT) provided the best plan for advanced NPC. What's more, plans of lung cancer showed VMAT in Monaco performed better than RapidArc of Eclipse, and no significant difference was found in IMRT plans of NPC. For the limited NPC cases (8 cases), the difference between VMAT and Rapidarc needed further study.

In China, many hospitals had two or more planning systems. When using automatic planning software in a multi-planning system center, it was necessary to consider the treatment benefits brought by the combination of treatment planning system and technology. The establishment of an automatic planning model relies on the completion of the plans by experienced physicists. And the choice of radiotherapy techniques for tumors at different sites depends on the clinical practices at the center and related dosimetric studies [27~35]. In this study, we investigated the appropriate systems and technologies for the lung cancer and NPC, as a reference for the technical choice of automatic planning.

5. Conclusions

Dosimetric analysis of lung cancer and NPC in Tomo, Monaco, and Eclipse shows that the VMAT plan of the Monaco is the best therapeutic schedule for lung cancer. For advanced NPC, the HT plan is the best option.

Abbreviations

NPC: Nasopharyngeal Carcinoma

IMRT: Intensity Modulated Radiation Therapy

VMAT: Volumetric Modulated Arc Therapy

GTV: Gross Tumor Volume

CTV: Clinical tumor volume

PTV: Planning Tumor Volume

OARs: Organ at Risks

DVH: Dose Volume Histogram

CI: Conformity Index

HI: Homogeneity Index

$D_{x\%}$: Dose receiving x% of the volume (e.g. $D_{95\%}$: dose receiving 95% of the volume)

$V_{x\%}$: Volume receiving x% of the prescription dose (e.g. $V_{95\%}$: Volume receiving95% of the prescription dose)

V_{xGy}: Volume receiving at least x Gy (e.g. V_{20Gy}: Volume receiving at least 20Gy)

D_{max}: Maximum Dose

D_{mean}: Mean Dose

HT: Helical Tomotherapy

Declarations

Authors' contributions

WJZ is responsible for data statistics and analysis, writing. MLW, JZ, YML are responsible for the designing of Eclipse plans, Tomo plans and Monaco plans, respectively. And LC, XY and SJH provide advice on the writing of the manuscript. XY and SJH are also involved in the writing and revision of the thesis.

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Availability of data and materials

The datasets are backed up on the Research Data Deposit public platform (RDD, http://www.researchdata.org.cn/, approval number :RDDB2019000733)and are available on reasonable request.

Ethics approval and consent to participate

All the data were retrospectively analyzed. This project was approved by the Ethical Committee of Sun Yat-Sen University Cancer Center and informed consent was exempted.

Consent for publication

All authors gave their consent for publication.

Competing interests

The authors declare that they have no competing interests.

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The datasets supporting the conclusions of this article are included within the article and its additional file.

Additional File

File name: Other files1

Type: PDF

Title of data & Description of data:

Table 1. Comparison of dosimetric parameters in OARs of lung cancer

Table 2. Comparison of dosimetric parameters in apart of targets and OARs of NPC

Figures

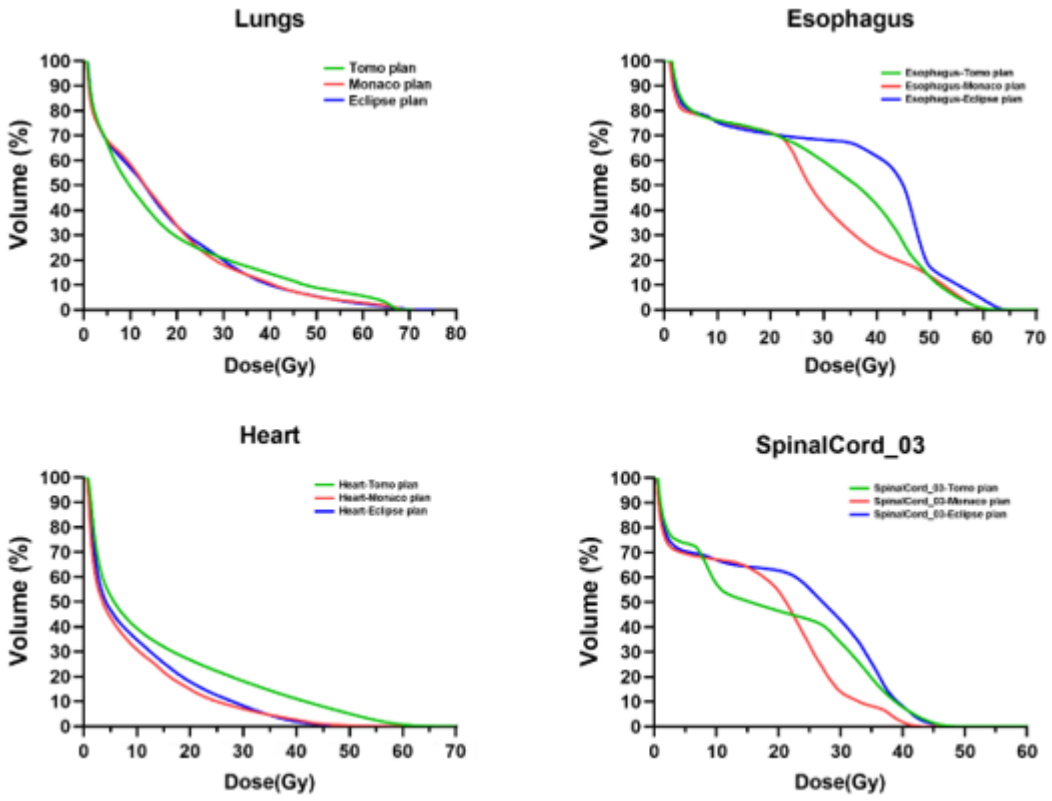

Figure 1

DVH of OARs for lung cancer

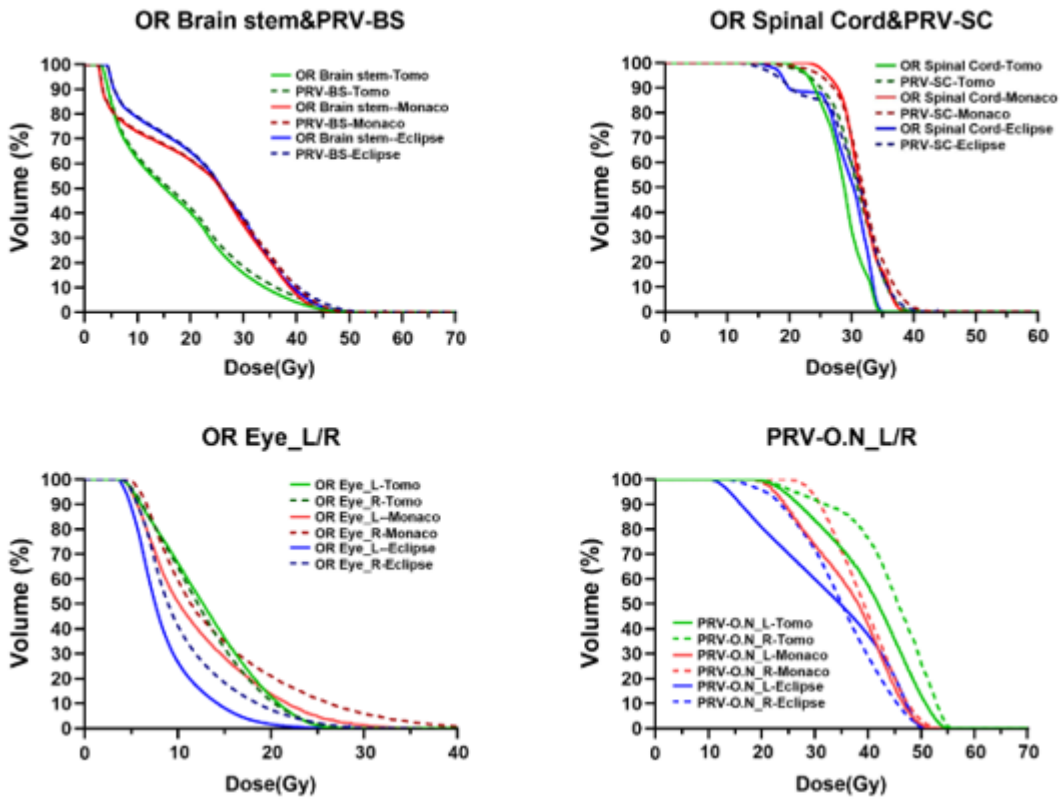

Figure 2

DVHs of OARs for NPC

Supplementary Files

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