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Influence of maximum MLC leaf speed on the quality of volumetric modulated arc therapy plans

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Abstract

Maximum leaf speed is a configurable parameter of MLC in treatment planning system. This study is to investigate its influence on the quality of VMAT plans.
Seven MLCs with different maximum leaf speeds (1.0, 1.5, 2.25, 3.5, 5.0, 7.5, 10 cm/sec) were configured for Linacs in TPS. Correspondingly, seven plans with the identical initial optimization parameter were designed with automatic planning system. Six NPC patients and nine rectal cancer patients were selected, which represented complex and simple clinical circumstances. VMAT plan quality was evaluated by score metrics. Two apparent trend of maximum MLC speed (MMLS) influence on plan quality were observed: Plan scores increase with MMLS; Plan scores increase rapidly when MMLS increases from 1 to 3.5, thus relative change of plan score decrease in these MMLS range. This work indicates MMLS direct influence on VMAT plan quality. VMAT plan quality was improved significantly in MMLS ranges 1 to 3.5, afterwards marginal improvement was observed.

Introduction

Due to the MLC's physical design, it has a great impact on VMAT radiation field. Rapid MLC speed could possibly improve plan quality. However, it could go too far, for the following three reasons.

- The fast leaf motion during gantry rotation may be affected by interleaf friction or MLC motor problems that result in leaf position errors.
- Both the dose rate and gantry speed in VMAT are allowed to vary, in addition to MLC leaf positions, to generate a highly conformal target dose distribution with minimal delivery time and monitor units (MU).
- As no thorough study about the benefit of MMLS in the LINAC, validating the optical maximum MLC leaf speed parameter for clinical implementation is of great interest in clinical practice.

The main objective of this research was to determine the influence of MMLS on plan quality.

Materials

MLC leaf speed simulation

Seven MLCs with different maximum leaf speeds (1.0, 1.5, 2.25, 3.5, 5.0, 7.5 & 10.0 cm/s) were configured with the Varian Novalis TX LINAC in the Pinnacle^3. Hereafter the MLCs are referred to as S1, S1.5, S2.25, S3.5, S5, S7.5 & S10, respectively.
MMLSs was 1~10 cm/s to cover all MMLS available in the LINAC market. The upper limit of MMLSs extent is 10 cm/s, far beyond the maximum values of MMLS in commercial LINAC to make sure this study reached MMLS large enough.

Patient information and target volume definition

Disease Sites: NPC		Target volume (cm^3)			
ID	Stage	PGTVnx	GTVnd	GTVrpn	PTV1
1	III	133.382	5.69809	3.37727	781.161
2	III	71.7462	1.53781	2.86533	597.127
3	IVA	90.0973	20.5975	0.643069	593.847
4	III	64．1844	10.7002	1.91473	899.005
5	III	50.7344	26.598	11.1814	789.998
6	III	58.6956	46.5409	4.96653	876.441

Disease Sites: Rectum		Target volume (cm^3)
ID	Stage	PTV
1	IIIB	1517.32
2	IIIA	1666.86
3	IIIB	1391.78
4	IIIB	1518.24
5	IIIC	1039.82
6	IIIB	1531.96
7	IIA	1533.82
8	IIIB	1728.24
9	IIIC	1609.31

Methodology

Planning method

The use of automated planning decreased inter-operator variability and guarantee high-quality VMAT treatment plans the in our study.

Plan evaluation and statistical analyses

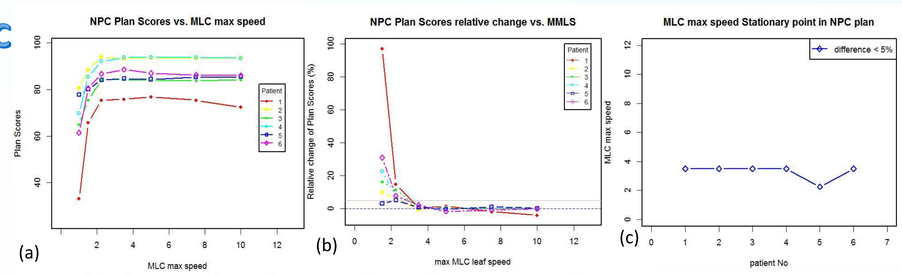
Plan quality was evaluated by plan scores which was introduced by by QUASI- MOD group in PlanIQ^{TM}
The nonparametric Kruskal-Wallis test was adopted for comparison.

Plan Quality Metric Component	Objective(s)	Score	
[ROI] Metirc	Endpoint [optimal]	mi n	ma x
[PTV] V[53.5Gy] (%)	< 10 [≤0.1]	0	3
[PTV] V[50.0Gy] (%)	> 94.5 [≥95]	0	4
[PTV] Homogeneity Index [50.0Gy]	< 1 [≤0]	0	3
[PTV] Conformation Number [50.0Gy]	> 0.65 [≥0.87]	0	3
[NT] V[10.0Gy] (%)	< 99 [≤70]	0	1
[NT] V[30.0Gy] (%)	< 50 [≤10]	0	1
[NT] V[20.0Gy] (%)	< 95 [≤50]	0	1
[NT] D[0.01cc] (Gy)	< 55 [≤47.5]	0	1
[INTESTINE] V[52.0Gy] (cc)	< 10 [≤0.01]	0	1
[INTESTINE] V[40.0Gy] (%)	< 20 [≤1]	0	2
[INTESTINE] V[30.0Gy] (%)	< 30 [≤5]	0	2
[FEMUR R] V[30.0Gy] (%)	< 50 [≤10]	0	1
[FEMUR R] Mean dose (Gy)	< 20 [≤12]	0	1
[FEMUR L] V[30.0Gy] (%)	< 50 [≤10]	0	1
[FEMUR L] Mean dose (Gy)	< 20 [≤12]	0	1
[COLON] V[52.0Gy] (cc)	< 20 [≤0.01]	0	1
[COLON] V[40.0Gy] (%)	< 30 [≤5]	0	2
[COLON] V[30.0Gy] (%)	< 60 [≤30]	0	2
[BLADDER] V[52.0Gy] (cc)	< 60 [≤1]	0	1
[BLADDER] V[40.0Gy] (%)	< 80 [≤40]	0	2
[BLADDER] V[30.0Gy] (%)	< 95 [≤60]	0	2
Total [21 Metrics]		0	36

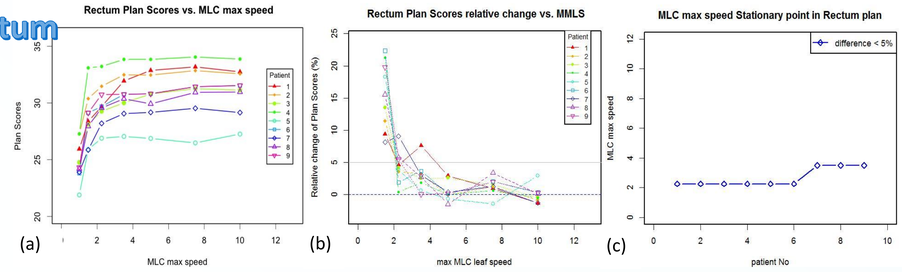
Plan Quality Metric Component	Objective(s)	Score	
[ROI] Metrics	Endpoint [optimal]	min	max
[BRAIN STEM PRV] V[60.0Gy] (cc)	< 10 [≤ 0.01]	0	2
[BRAIN STEM] V[54.0Gy] (cc)	< 10 [≤ 0.01]	0	4
[GTVND] Homogeneity Index# [69.96Gy]	< 1 [≤ 0]	0	3
[GTVND] V[69.96Gy] (%)	> 94.5 [≥ 95]	0	5
[GTVND] V[74.86Gy] (cc)	< 10 [≤ 1]	0	2
[GTVND+(PGTVNX+GTVRPN+0.3)] Conformation Number [69.96Gy]	> 0.25 [≥ 0.85]	0	2
[GTVRPN] Homogeneity Index [73.92Gy]	< 1 [≤ 0]	0	3
[GTVRPN] V[73.92Gy] (%)	> 94.5 [≥ 95]	0	5
[GTVRPN] V[79.09Gy] (cc)	< 10 [≤ 1]	0	3
[LARYNX] V[40.0Gy] (%)	< 60 [≤ 30]	0	2
[LENS L] V[9.0Gy] (cc)	< 0.1 [≤ 0.01]	0	3
[LENS R] V[9.0Gy] (cc)	< 0.1 [≤ 0.01]	0	3
[MANDIBLE L] V[60.0Gy] (%)	< 20 [≤ 5]	0	2
[MANDIBLE R] V[60.0Gy] (%)	< 20 [≤ 5]	0	2
[NT] D[0.01cc] (Gy)	< 66.07 [≤ 57.06]	0	1
[NT] V[20.0Gy] (%)	< 90 [≤ 50]	0	1
[NT] V[30.0Gy] (%)	< 80 [≤ 20]	0	1
[OPTIC CHIASM] V[54.0Gy] (%)	< 1 [≤ 0]	0	2
[OPTIC NERVE L] V[54.0Gy] (%)	< 10 [≤ 0.1]	0	2
[OPTIC NERVE R] V[54.0Gy] (%)	< 10 [≤ 0.1]	0	2
[PAROTID L] V[20.0Gy] (%)	< 90 [≤ 60]	0	1
[PAROTID L] V[30.0Gy] (%)	< 65 [≤ 45]	0	2
[PAROTID R] V[20.0Gy] (%)	< 90 [≤ 60]	0	1
[PAROTID R] V[30.0Gy] (%)	< 65 [≤ 45]	0	2
[PGTVNX] Homogeneity Index [73.92Gy]	< 1 [≤ 0]	0	3
[PGTVNX] V[73.92Gy] (%)	> 94.5 [≥ 95]	0	5
[PGTVNX+GTVRPN] Conformation Number [73.92Gy]	> 0.25 [≥ 0.85]	0	4
[PGTVNX+GTVRPN] V[79.09Gy] (%)	< 50 [≤ 10]	0	3
[PTV1-(PGTVNX+GTVRPN+GTVND)] Homogeneity Index [60.06Gy]	< 1 [≤ 0]	0	3
[PTV1-(PGTVNX+GTVRPN+GTVND)] V[64.26Gy] (%)	< 80 [≤ 10]	0	3
[PTV1] Conformation Number [60.06Gy]	> 0.65 [≥ 0.87]	0	2
[PTV1] V[60.06Gy] (%)	> 94.5 [≥ 95]	0	5
[SPINAL CORD PRV] V[45.0Gy] (cc)	< 0.1 [≤ 0]	0	2
[SPINAL CORD] V[40.0Gy] (cc)	< 0.1 [≤ 0]	0	4
[TEMPORAL LOBE L] V[54.0Gy] (%)	< 5 [≤ 1]	0	2
[TEMPORAL LOBE R] V[54.0Gy] (%)	< 5 [≤ 1]	0	2
[THYROID GLAND] V[40.0Gy] (%)	< 70 [≤ 40]	0	2
[TMJ L] V[50.0Gy] (%)	< 40 [≤ 1]	0	2
[TMJ R] V[50.0Gy] (%)	< 40 [≤ 1]	0	2
[TRACHEA] V[40.0Gy] (%)	< 70 [≤ 10]	0	2
Total [40 Metrics]		0	102

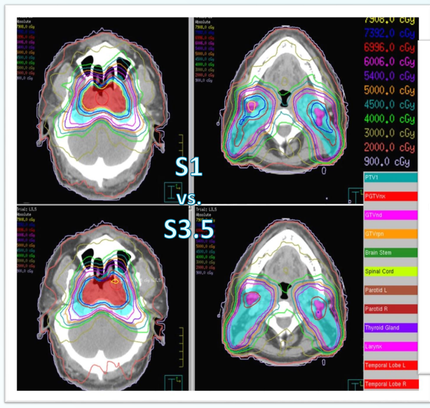
Results

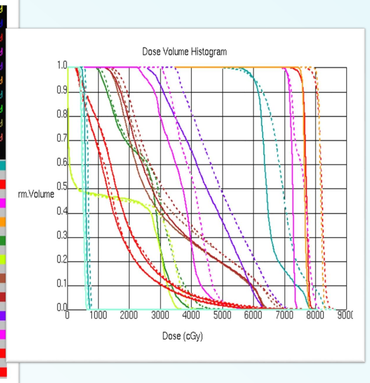
NPC



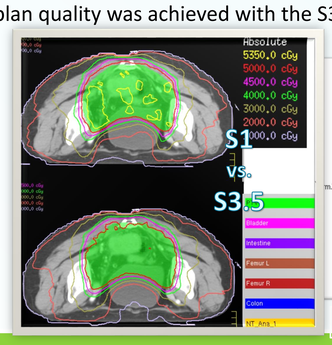
Rectum

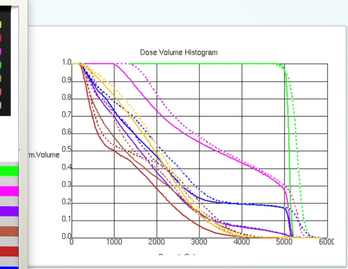






- ✓ S3.5 plan： achieved better conformity to target, fewer hot spots, produced steeper DVHs in the high-dose ranges. For selected OARs, OARs volume was smaller in the inter-median dose range.
- ✓ Better plan quality was achieved with the S3.5 plan than S1 plan.





S1: dashed lines S3.5: solid lines

PQM scores vs. MMLS	The relative change of PQM scores vs. MMLS	MMSSP values vs. MMLS
Both NPC & Rectal: • Scores dramatically increased as MMLS 1 cm/s increased -> 3.5 cm/s. • Scores increased slowly when MMLS increased > 3.5 cm/s.	• NPC: declined when MMLS < 3.5 cm/s, decreased slightly when MMLS > 3.5 cm/s. • Rectal: decreased vs. MMLS when MMLS was below 2.25 cm/s. After that, mostly within 5%.	• MMSSP: specific MMLS at which the relative change of plan scores first drops in a tiny interval (less than 5%) • Rectal: 2.25 for six patients (66.67% of total) & 3.5 for the other three patients. • NPC: 3.5 for five patients (83.33% of total) & 2.25 for the other patient.

Discussion

Chen et al. found that MMLS was a significant impact on the quality, efficiency and accuracy of the plans delivered, especially in complex treatments IMAT plan.

Their studies were based on IMAT, whereas VMAT is an improved technique. Our results showed that as MMLS increased, so did VMAT plan quality, resulting in better conformity, more homogenous dose distributions and higher plan quality., MMSSPs were 2.25 ~ 3.5 for both simple and complex clinical scenarios.

The statistical results of plan scores from seven MMLS type plans in both rectal cases and NPC cases were consistent with MMSSP result. 1) Rectal cancer cases: S1 plan was significantly difference to S2.25, S3.5, S5, S7.5, S10 plans methods ($P < 0.01$). 2) NPC cases, S1 plan was significantly difference to other five MMLS plans methods ($P < 0.01$). 3)While other MMLS plans did not differ significantly from each other.

Conclusion

This work indicates that the maximum leaf speed of MLCs has an apparent influence on the quality of VMAT plans. The quality of VMAT plans is greatly improved as MMLS increases from 1 cm/s to 3.5 cm/s; above that, the quality change is marginal.

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