基于不同多叶准直器的胸膜间皮瘤容积旋转调强放疗剂量学比较

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【摘　要】**目的：**比较基于两种类型多叶准直器（Multileaf Collimator, MLC）的胸膜间皮瘤容积旋转调强放疗（Volumetric Modulated Arc Therapy, VMAT）计划差异。**材料与方法：**回顾性选取10例因各种无法手术的胸膜间皮瘤患者CT图像，分别采用配置常规多叶准直器（Standar MLC, sMLC）和微型多叶准直器（micro-MLC, mMLC）的医科达直线加速器进行VMAT的计划设计。比较两种计划在靶区（Planning Target Volume, PTV）适形度（Conformity Index, CI）、均匀度（Heterogeneity Index, HI）以及危及器官（Organs At Risk, OAR）剂量体积参数方面的异同。**结果：**与基于sMLC的VMAT计划（sMLC-VMAT）相比，基于mMLC的VMAT计划（mMLC-VMAT）实施效率高（平均实施时间：2.57±1.66 min *vs* 3.27±1.65 min, $P<0.05$）。此外，mMLC-VMAT计划靶区适形度和均匀度优于sMLC-VMAT（CI：0.75±0.08 *vs* 0.71±0.12；HI：1.09±0.02 *vs* 1.11±0.03）。就OARs而言，除心脏的D_{mean}（$P=0.042$）以外，其它各个OARs的剂量体积参数差异均无显著性意义（$P>0.05$）。**结论：**与sMLC-VMAT计划相比，mMLC-VMAT计划不仅明显缩短了治疗时间，提高靶区的覆盖度与均匀性，而且显著降低了心脏的平均受照剂量，有助于减小心血管病的发生风险。

【关键词】多叶准直器；胸膜间皮瘤；容积旋转调强放疗；放疗剂量
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Dosimetric comparison of volumetric-modulated arc therapy with different multileaf collimators for pleural mesothelioma

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Abstract: Objective To compare the differences of two types of multileaf collimators (MLC) in the volumetric modulated arc therapy (VMAT) plan for pleural mesothelioma. **Methods** The CT images of ten patients with inoperable pleural mesotheliom were retrospectively selected. The Elekta linear accelerator with Standar MLC (sMLC) and Micro-MLC (mMLC) were respectively applied to design VMAT treatment plans. The conformity index (CI) and homogeneous index (HI) of planning target volume (PTV), and the dose-volume parameters of organs at risk (OARs) were compared between the VMAT plan with sMLC (sMLC-VMAT) and VMAT plan with mMLC (mMLC-VMAT). **Results** The delivery time of sMLC-VMAT and mMLC-VMAT was 3.27 min±1.65 min and 2.57 min±1.66 min, respectively. Compared with sMLC-VMAT, mMLC-VMAT was more efficient ($P<0.05$). And the CI of sMLC-VMAT and mMLC-VMAT was 0.71±0.12, 0.75±0.08, respectively, while the HI was 1.11±0.03, 1.09±0.02, respectively. Both HI and CI of mMLC-VMAT were better than those of sMLC-VMAT. No significant differences were found in the dose-volume parameter of OARs ($P>0.05$), except the mean dose of heart ($P=0.042$). **Conclusion** Compared with the sMLC-VMAT, mMLC-VMAT can reduce the treatment delivery time, improve the coverage and HI of target volumes, significantly reduce the average irradiation dose to heart, and lower the risk of cardiovascular disease.
Key words: multileaf collimator; pleural mesothelioma; volumetric modulated arc therapy; radiotherapic dosimetry

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前　言

恶性胸膜间皮瘤（Malignant Pleural Mesothelioma, MPM）发生率低，病变广泛并具有明显的症状，一般预后较差。早期回顾性分析显示5年生存率仅为1%

左右，平均存活时间不超过7.6个月[1]。目前，单纯手术、化疗以及放疗都没有显著提高MPM的生存率，故而临床上尝试了多种综合治疗方案[2-5]。对于早期病变，全胸膜肺切除术配合放化疗辅助性治疗是较好的选择。然而，大多数病例(70%~80%)在确诊时已无法手术，此时通常需要接受姑息性放疗[6]。

容积旋转调强(Volumetric Modulated Arc Therapy, VMAT)是在固定野调强放疗(Intensity Modulated Radiation Therapy, IMRT)和影像引导放射治疗(Image Guided Radiation Therapy, IGRT)技术发展的基础上，随着计算机、放疗技术以及放疗设备的改进而产生的更为先进的新技术。该技术与以往的三维适形放疗(Three Dimensional Radiation Therapy, 3DCRT)、IMRT等精确放疗技术的不同点在于，通过同时改变机架的旋转速度、多叶准直器(Multileaf Collimator, MLC)叶片位置以及剂量率大小实现高度适形的治疗计划实施。VMAT技术已在各种肿瘤治疗上获得了良好的效益[7-11]。

本文通过对基于配置不同类型MLC的Elekta Synergy、Elekta Axesse(Elekta AB, Stockholm, Sweden)两种加速器设计的胸膜间皮瘤VMAT放疗计划的分析，比较了两种计划在靶区剂量均匀性、适形度以及危及器官受照体积和剂量分布方面的差异，为在临床应用和设备选购时选择何种类型MLC提供参考。

1 材料与方法

1.1 一般临床资料

选择2006年9月~2013年5月确诊MPM但因各种原因无法接受手术而行姑息性放疗的10例患者作为研究对象，中位年龄48.5岁。通过模拟CT扫描生成患者的三维治疗计划用于本研究。

1.2 CT模拟定位

首先对患者治疗部位行CT螺旋扫描，CT扫描采用Philips公司85 cm大孔径CT模拟定位机(ACQSim Philips Medical systems, Cleveland, the USA; Brilliance Big Bore CT, Philips Medical systems, Cleveland, the USA)。患者仰卧位，双臂上抬交叉置额顶，以患者放疗体位制作胸部热塑模，以体架固定，扫描时层厚5 mm，层间距5 mm。扫描范围上界至环状软骨，下界至肾上腺。扫描图像经局域网传输至Monaco 5.0计划工作站(Elekta AB, Stockholm, Sweden)。

1.3 靶体积及危及器官的界定

扫描后CT图像由网络传输至Monaco 5.0计划工作站，由专业放疗医师参考ICRU第62号报告[12]勾画出大体肿瘤(GTV)、计划靶区(PTV)及危及器官(OARs)，包括脊髓、心脏、GTV外的肺组织，将脊髓外放5 mm得到危及器官计划靶区(PRV)。GTV包括临床和影像学所见肿瘤范围，PTV由GTV外放得到，向胸膜方向外放10 mm，向肺部方向外放5 mm。处方剂量为60 Gy(注：处方剂量是指95%的PTV所受到的最低剂量)，分割次数为30次。

1.4 治疗计划设计

分别采用Elekta Synergy(40对MLC，叶片在等中心宽度为10 mm)、Elekta Axesse(80对MLC，叶片在等中心宽度为5 mm)加速器6 MV X射线，所有计划均在Monaco 5.0工作站上完成。基于两种加速器，对每个患者设计双弧VMAT计划，起始角度和终止角度均为180°，机架顺时针旋转。以PTV为参考体积，要求95%的PTV达到处方剂量60 Gy，OARs剂量和体积限制条件见表1。

表1 危及器官剂量体积限制条件

Tab.1 Dose–volume constraint conditions of organs at risk (OARs)

OARs	Dose (Gy)	Volume (%)
Ipsilateral lung	20	<80
	10	<85
Contralateral lung	25	<30
Heart	30	<50
Spinal cord	45	<10

1.5 计划比较

对两种治疗计划在靶区剂量分布，包括靶区最大剂量(D_{max})、平均剂量(D_{mean})、最小剂量(D_{min})，均匀性指数(Heterogeneity Index, HI)[13]、适形度指数(Conformity Index, CI)[13]，靶区和危及器官剂量体积直方图参数的差别进行比较。正常组织分析指标为受特定剂量水平照射的体积百分比。

1.6 统计方法

用SPSS18软件对两种计划结果比较行Student *t*检验。

2 结　果

2.1 PTV剂量分布

两种能量放疗计划的PTV剂量分布见表2。PTV的最大剂量(D_{max})是指小于等于2% PTV的体积接受的剂量[11]。本研究中，两种能量放疗计划的D_{max}差异有显著性意义(P=0.05)。PTV的最小剂量(D_{min})

是指大于等于98% PTV的体积接受的剂量。本研究中，两种能量放疗计划的D_{min}差异有显著性意义（P=0.043）。此外，PTV平均剂量D_{mean}的差异无显著性意义（P=0.056）。

表2 两种计划PTV剂量分布 ($\bar{x}\pm s$)

Tab.2 Dose distribution of PTV of Synergy and Axesse- based VMAT plans (*Mean±SD*)

Parameter	Elekta Synergy	Elekta Axesse	*t*	*P*
D_{max}	67.22±2.21	66.25±1.66	2.258	0.05
D_{min}	58.61±0.72	58.93±0.59	-2.352	0.043
D_{mean}	63.27±1.04	62.78±0.73	2.195	0.056

Note: PTV: Planning target volume; VMAT: Volumetric modulated arc therapy

2.2 PTV靶区均匀指数、适形指数

两种放疗计划在HI和CI方面差异均有显著性意义（P=0.05, P=0.033），基于Axesse加速器的VMAT治疗计划的HI和CI均显著优于基于Synergy加速器的VMAT计划，详见表3。

表3 两种计划靶区均匀性和适形度 ($\bar{x}\pm s$)

Tab.3 HI and CI of treatment plans with different MLC (*Mean±SD*)

Index	Elekta Synergy	Elekta Axesse	*t*	*P*
HI	1.11±0.03	1.09±0.02	2.264	0.05
CI	0.71±0.12	0.75±0.08	-2.520	0.033

Note: HI: Homogeneity index; CI: Conformity index; MLC: Multileaf collimator

2.3 危及器官剂量、体积参数

患侧肺、对侧肺、心脏、脊髓的剂量和受照体积参数见表4。

表4 两种治疗计划危及器官剂量体积参数比较 (%, $\bar{x}\pm s$)

Tab.4 Comparison of dose-volume parameters of OARs of two plans (%, *Mean±SD*)

OARs	Parameter	Elekta Synergy	Elekta Axesse	*t*	*P*
Ipsilateral lung	V_5	83.37±21.08	82.61±21.51	1.045	0.323
	V_{10}	75.41±25.24	73.56±25.38	1.825	0.101
	V_{20}	57.13±29.44	54.72±27.08	1.709	0.122
	V_{30}	44.68±30.77	42.74±27.86	-0.780	0.455
Contralateral lung	V_3	79.93±26.09	80.11±26.35	-0.732	0.483
	V_5	73.89±29.72	73.59±30.21	0.662	0.524
	V_{10}	46.69±24.54	47.90±27.39	-0.780	0.455
	V_{20}	12.94±11.40	12.81±11.78	0.085	0.934
Heart	V_5	71.93±44.88	71.28±45.28	1.914	0.088
	D_{mean}	22.15±16.44	20.36±15.13	2.375	0.042
Spinal cord	D_{max}	36.16±10.45	36.22±10.97	-0.069	0.947

Note: V_5: Volume percentage of receiving the irradiation of 5 Gy. The followings are similar.

2.4 MU和治疗时间

两种治疗计划的MU数和治疗时间见表5。

表5 两种治疗计划的MU和治疗时间 ($\bar{x}\pm s$)

Tab.5 Comparison of MU and treatment delivery time (*Mean±SD*)

Index	Elekta Synergy	Elekta Axesse	*t*	*P*
MU	907.6±378.9	962.1±489.2	-1.436	0.185
Treatment delivery time (min)	3.27±1.65	2.57±1.66	3.458	0.007

Note: MU: Monitor unit

3 讨 论

MLC的设计构造对放射治疗的实施和效果有着重要影响。Gong等[14]研究表明宽度较小的MLC能够提高靶区的适形度。本研究中，基于配置不同类型MLC的Elekta Synergy、Axesse两种加速器设计的胸膜间皮瘤VMAT放疗计划靶区的适形和均匀度差异均有统计学意义，采用基于mMLC（所有叶片在等中心宽度为5 mm）的Axesse加速器的放疗计划的HI和CI均明显优于采用sMLC（所有叶片在等中心宽度为10 mm）的Synergy加速器，表明宽度较小的MLC叶片有助于获得均匀的靶区剂量分布和适形度。另一方面，对于危及器官而言，除心脏D_{mean}外，两种放

疗计划的差异均无统计学意义。基于mMLC的VMAT计划的MU数较之基于SMLC的VMAT计划增加约6%,但治疗实施时间反而降低了21.4%,原因可能在于:(1)较早期的Elekta Synergy加速器仅支持剂量率分段变化(Binned Dose Rate, BDR),仅有600 MU/min、300 MU/min、150 MU/min、75 MU/min、37 MU/min五档剂量率变化;而Elekta Axesse加速器采用Integrity治疗控制系统,此系统支持剂量率连续变化(Continuous Variable Dose rate, CVDR),剂量率从45 MU/min至660 MU/min可变,从而有助于降低治疗时间[15];(2)mMLC采用交叉式(Interdigitation)运动方式,叶片最大移动速度可达3.5 cm/s,而sMLC的叶片最大移动速度仅为2 cm/s,故而采用mMLC叶片较之采用sMLC可进一步缩短治疗时间。综上所述,采用mMLC叶片时能够获得更好的靶区覆盖和均匀性,而且可以缩短治疗时间,有助于提高患者治疗时的舒适度和重复性。

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