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胸膜间皮瘤螺旋断层调强放疗和容积旋转调强放疗的剂量学评估

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【摘　要】目的:比较螺旋断层调强放疗(Helical Tomotherapy, HT)和容积旋转调强放疗(Volumetric Modulated Arc Therapy, VMAT)在恶性胸膜间皮瘤放疗中的治疗计划差异。**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HT和医科达Synergy VMAT直线加速器进行旋转调强放疗的计划设计。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:**HT计划靶区CI和HI均显著优于VMAT计划(HI:1.04±0.01 *vs* 1.11±0.03;CI:0.80±0.07 *vs* 0.71±0.12)(*P*=0.000, *P*=0.013)。就OARs而言,HT在患侧肺V_5、V_{10}、V_{20}、V_{30},健侧肺V_3、V_5、V_{10}、V_{20},心脏V_5、D_{mean},脊髓D_{max}均低于VMAT,其中患侧肺V_{30}、健侧肺V_5、V_{10}、V_{20}的差异有显著性意义(*P*=0.031, *P*=0.030, *P*=0.021, *P*=0.003)。而VMAT计划的实施效率则远高于HT计划(平均实施时间:3.27±1.65 min *vs* 11.11±3.75 min)(*P*=0.000)。**结论:**与VMAT计划相比,HT提高了靶区的覆盖度与均匀性,而且降低了患侧肺、健侧肺、心脏的剂量体积参数,有助于减小放射性损伤的发生风险。但HT计划的治疗实施时间较VMAT计划明显延长。

【关键词】螺旋断层放疗;胸膜间皮瘤;容积旋转调强放疗;剂量学
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Dosimetric evaluation of helical tomotherapy and volumetric-modulated arc therapy for pleural mesothelioma

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Abstract: Objective To compare differences of helical tomotherapy (HT) and volumetric-modulated arc therapy (VMAT) for malignant pleural mesothelioma. **Methods** The CT images of ten patients with inoperable pleural mesotheliom were retrospectively selected. The HT and Synergy VMAT linear accelerator of Elekta were respectively applied to design treatment plans. The conformity index (CI) and heterogeneity index (HI) of planning target volume (PTV), and the dose-volume parameters of organs at risk (OARs) were compared between these two plans. **Results** The HI and CI of HT plan were respectively 1.04±0.01, 0.80±0.07, while those of VMAT plan based on Elekta Synergy were respectively 1.11±0.03, 0.71±0.12, with significant differences (*P*=0.000, *P*=0.013). For OARs, V_5, V_{10}, V_{20}, V_{30} of ipsilateral lung, and V_3, V_5, V_{10}, V_{20} of contralateral lung, and V_5, mean dose (D_{mean}) of heart, and maximum dose (D_{max}) of cord in HT plan were all lower than those of VMAT plan. And there were significant differences in V_{30} of ipsilateral lung, and V_5, V_{10}, V_{20} of contralateral lung (*P*=0.031, *P*=0.030, *P*=0.021, *P*=0.003). However, the mean delivery time of VMAT plan and HT plan were respectively 3.27±1.65 min, 11.11±3.75 min, which meaned the efficiency of VMAT plan was higher than that of HT plan (*P*=0.000). **Conclusion** Compared with VMAT plan, HT plan increases the coverage and HI of target volumes, and lowers the dose-volume parameters of ipsilateral lung, contralateral lung and heart, reducing the risk of radioactive injury. But the treatment delivery time of HT plan is significantly longer than that of VMAT plan.

Key words: helical tomotherapy; pleural mesothelioma; volumetric-modulated arc therapy; dosimetry

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前 言

恶性胸膜间皮瘤(Malignant Pleural Mesothelioma, MPM)发生率低,发现时多为病变广泛,症状较明显,预后差。早期的回顾性分析显示5年生存率为1%左右,平均存活时间不超过7.6个月[1]。目前,单一的手术、化疗和放疗都没有明显提高MPM的生存率, 因而人们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]。

螺旋断层加速器(Helical TomoTherapy, HT)是将螺旋CT技术与直线加速器技术整合在一起的调强放疗系统[7-9]。TOMO的出束方式为切片式,在360°范围内全角度实施照射,照射过程中,机架旋转、床运动、加速器脉冲和二元气动多叶准直器(MLC)的开闭保持同步[10]。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。VMAT技术已在各种肿瘤治疗上获得了良好的效益[11-15]。

本文通过对基于HT的放疗计划和基于Elekta Synergy(Elekta AB, Stockholm, Sweden)加速器设计的VMAT放疗计划的分析,比较了两种计划在MPM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,为在临床应用提供剂量学参考依据。

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 Ssystems, 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体模,用体部固定器固定,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[16]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

HT治疗计划在其治疗计划系统Hi-Art®4.1.2(Madison, USA, Version 4.1.2)上完成,VMAT计划在Monaco 5.0工作站上完成。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列于表1中。

表1 危及器官剂量体积限制条件

Tab.1 Dose-volume constraint for OARs

OARs	Dose (Gy)	Volume (%)
Ipsilateral lung	20	<50
	10	<70
Contralateral lung	10	<40
Heart	5	<50
Cord	45	<1

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)[17]、适形度指数(Conformity Index, CI)[17],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

采用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[15]。本研究中,两种能量放疗计划的D_{max}差异有显著性意义(P=0.000)。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=0.011)。此外,PTV平均剂量(D_{mean})的差异有显著性意义(P=0.000)。

表2 两种计划PTV剂量分布 (Gy, $\bar{x}\pm s$)

Tab.2 Dose distribution of PTV in HT plan and VMAT plan (Gy, *Mean±SD*)

Parameter	HT	VMAT	*t* value	*P* value
D_{max}	63.15±0.99	67.22±2.21	-7.567	0.000
D_{min}	59.26±0.46	58.61±0.72	3.217	0.011
D_{mean}	61.82±0.68	63.27±1.04	-5.678	0.000

2.2 PTV靶区HI、CI

两种放疗计划在HI和CI方面差异均有显著性意义(P=0.000, P=0.013),HT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 PTV in HT plan and VMAT plan (*Mean±SD*)

Index	HT	VMAT	*t* value	*P* value
HI	1.04±0.01	1.11±0.03	-8.913	0.000
CI	0.80±0.07	0.71±0.12	3.087	0.013

Note: HI: Heterogeneity index; CI: Conformity index

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。

2.4 MU和治疗时间

两种治疗计划的MU数和治疗时间如表5所示。

3 讨 论

HT和VMAT均是通过提高PTV的适形度以增加照射剂量,并尽可能减少正常组织照射体积和剂量,从而提高放疗的治疗增益比。本研究中,我们发现HT与VMAT放疗计划的HI和CI的差异有显著性意义,前者明显优于后者。

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 OARs dose-volume parameters (%, *Mean±SD*)

OARs	Parameter	HT	VMAT	*t* value	*P* value
Ipsilateral lung	V_5	79.64±21.80	83.37±21.08	-1.504	0.167
	V_{10}	73.32±25.14	75.41±25.24	-0.675	0.517
	V_{20}	51.23±26.72	57.13±29.44	-2.088	0.066
	V_{30}	37.38±23.58	44.68±30.77	-2.561	0.031
Contralateral lung	V_3	72.87±30.64	79.93±26.09	-2.002	0.076
	V_5	63.19±34.60	73.89±29.72	-2.571	0.030
	V_{10}	29.89±29.88	46.69±24.54	-2.779	0.021
	V_{20}	4.45±6.47	12.94±11.40	-3.993	0.003
Heart	V_5	65.62±45.96	71.93±44.88	-1.181	0.268
	D_{mean}	17.76±13.69	22.15±16.44	-1.818	0.102
Cord	D_{max}	32.45±12.93	36.16±10.45	-1.726	0.118

MPM往往病灶范围较大,故而在放疗过程中患侧肺、健侧肺、心脏等正常组织不可避免地会受到一定剂量的照射,造成不同程度的放射损伤。本文中,我们比较了分别采用HT和VMAT放疗技术的治疗计划,发现HT计划无论在低剂量区域还是高剂量区域对各OARs的受照剂量体积参数均小于VMAT计划。患侧肺V_{30}、健侧肺V_5、V_{10}、V_{20}参数的差异有显著性意义(P=0.031、P=0.030、P=0.021、P=0.003)。Langen[18],

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*)

	HT	VMAT	*t* value	*P* value
MU	9776.8±3301.6	907.6±378.9	8.454	0.000
Treatment time (min)	11.11±3.75	3.27±1.65	5.995	0.000

Note: MU: Monitor unit

Schllenkamp等[19]的研究表明,小剂量大体积的肺照射比大剂量小体积的肺照射对肺功能的损伤更大,建议将V_5控制在60%以内。本研究中,HT和VMAT计划的患侧肺和健侧肺的V_5分别达到了79.64%、63.19%和83.37%、73.89%。近年来,HT和VMAT的低剂量受照体积较高所引发的放射性损伤越来越引起国内外专家学者的关注,因此对应用HT或VMAT治疗MPM应持相对谨慎态度。就治疗实施时间而言,VMAT所需时间远低于HT所需时间,从而有助于提高患者放疗时的舒适度和重复性。

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