

胃癌术后调强放疗射野角度优化的剂量学

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【摘要】目的:比较胃癌术后放疗射野角度优化和传统布野方法的剂量学差异。**方法:**选择8例胃癌术后患者分别制定射野均分(EGA)、人工布野(MBS)、射野角度优化(BAO)调强放疗计划,对靶区和危及器官的剂量学数据进行配对 t 检验,比较射野角度分布差异。**结果:**EGA与BAO比较,肝脏 D_{mean} (21.77%, $P=0.003$)、 V_{10} (31.68%, $P=0.004$)、 V_{20} (37.87%, $P=0.006$);双肾 D_{mean} (23.83%, $P=0.039$)、 V_{10} (31.51%, $P=0.024$)、 V_{15} (60.60%, $P=0.026$)、 V_{20} (70.45%, $P=0.018$);胃 D_{mean} (7.25%, $P=0.025$)、 V_{10} (3.78%, $P=0.027$);双肺 D_{mean} (10.23%, $P=0.024$)、 V_{10} (20.18%, $P=0.035$);Body-PTV D_{mean} (7.57%, $P=0.006$)、 V_5 (10.26%, $P=0.005$)、 V_{10} (12.20%, $P=0.010$),差异有统计学意义,BAO组优于EGA组。MBS与BAO比较,双肾 V_{15} (36.54%, $P=0.032$)、 V_{20} (43.97%, $P=0.034$);胃 D_{mean} (3.93%, $P=0.035$)、 V_{10} (2.86%, $P=0.038$),差异有统计学意义,BAO组优于MBS组。EGA与BAO计划的射野角度差异要明显大于MBS与BAO计划的差异。**结论:**胃癌术后放疗中,BAO计划可更好地保护危及器官。

【关键词】射野角度优化;胃癌;调强放射治疗;剂量学

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Dosimetric investigation of beam angle optimization in postoperative intensity modulated radiation therapy for gastric cancer

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Abstract: Objective To compare the dosimetric difference of beam angle optimization (BAO) and traditional beam configuration in postoperative intensity modulated radiation therapy (IMRT) for gastric cancer. **Methods** Equally-spaced gantry angles (EGA) plans, manual beam angle selection (MBS) plans and BAO plans were respectively designed for selected eight postoperative patients with gastric cancer. Dosimetric results of target volumes and organs at risk (OARs) were examined by paired t -test to compare the difference of beam angle distribution. **Results** BAO plans were better than EGA plans, with significant differences. For livers, the difference percentage of mean dose (D_{mean}) was 21.77% ($P=0.003$), and that of V_{10} was 31.68% ($P=0.004$), and that of V_{20} was 37.87% ($P=0.006$). For bilateral kidneys, the difference percentage of D_{mean} was 23.83% ($P=0.039$), and that of V_{10} was 31.51% ($P=0.024$), and that of V_{15} was 60.60% ($P=0.026$), and that of V_{20} was 70.45% ($P=0.018$). For stomach, the difference percentage of D_{mean} was 7.25% ($P=0.025$), and that of V_{10} was 3.78% ($P=0.027$). For lungs, the difference percentage of D_{mean} was 10.23% ($P=0.024$), and that of V_{10} was 20.18% ($P=0.035$). For body planning target volume, the BAO plans provided lower D_{mean} (7.57%, $P=0.006$), V_5 (10.26%, $P=0.005$) and V_{10} (12.20%, $P=0.010$). Compared with MBS plans, BAO plans were also better, with significant differences. BAO plans provided significant lower V_{15} (36.54%, $P=0.032$) and V_{20} (43.97%, $P=0.034$) for bilateral kidneys, and lower D_{mean} (3.93%, $P=0.035$) and V_{10} (2.86%, $P=0.038$) for stomach. The gantry angle difference between EGA plans and BAO plans were more evident than that between MBS plans and BAO plans. **Conclusion** BAO plans provide better protections for OARs in postoperative IMRT for gastric cancer.

Key words: beam angle optimization; gastric cancer; intensity modulated radiation therapy; dosimetry

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前言

目前手术是治疗胃癌最主要和最有效的手段,但随着放疗设备和技术的不断发展更新,特别是精确放疗的出现,胃癌放疗的疗效有了较大程度的提高,已有文献报道术后辅助放疗能够提高胃癌的局控率和生存率^[1]。调强放疗(IMRT)与三维适形治疗(3DCRT)相比,IMRT能够进一步提高靶区的适形度和剂量均匀性,而且可以更好地保护胃癌靶区附近的肝脏、小肠、双肾、胃、脊髓等正常组织,有着更高的治疗增益比^[2]。同时IMRT的计划设计也更为复杂,在射野投射角度的选取上要求计划设计者具备丰富的经验。射野角度优化(BAO)是逆向IMRT的进一步拓展,其由计划设计的目标出发,通过逆向优化算法搜索最优的射束角度^[3-4]。国内外已有文献报道BAO在头颈部放疗中可以减少射野数目^[5],在非小细胞肺癌放疗中使用较少的射野数可获得相似的剂量分布^[6],在腹部肿瘤放疗中能够降低危及器官和全身剂量^[7],相对于均分布野方式可以提升放疗计划质量^[8-9]。本文将通过比较3种放疗计划的剂量学结果,研究BAO对胃癌术后IMRT计划的剂量学改善。

1 材料与方法

1.1 患者选择

选择8例胃癌术后患者(男性6例,女性2例);年龄范围55岁~69岁,中位年龄为63岁;病理类型均为腺癌,T₃、T₄,N⁺患者(2010 UICC/AJCC)。所有患者定位都采取仰卧位,双臂上举抱头,使用体部热塑模固定体位,患者在平静自由呼吸状态下行CT增强扫描,扫描层厚为5 mm。

1.2 靶区、危及器官勾画

CT影像由网络传至Varian Eclipse 8.6治疗计划系统,所有患者均匀画大体肿瘤体积(Gross Tumor Volume, GTV),临床靶体积(Clinical Target Volume, CTV)包括瘤床、残胃或吻合口和相应的淋巴引流区,计划靶体积(Planning Target Volume, PTV)在CTV基础上均匀外放0.5 cm。PTV给予总剂量为45 Gy,1.8 Gy/次,保护肝脏、双肾、小肠、胃、脊髓、双肺、心脏等危及器官。

1.3 计划设计与评估

计划使用6 MV X射线,各向异性解析剂量算法(Anisotropic Analytical Algorithm, AAA),计算分辨率2.5 mm。布野方法:5野均分布野(EGA),机架角度为0°、72°、144°、216°、288°。由具有丰富计划设计

经验的物理师人工布野(MBS)设计共5野。使用治疗计划系统BAO模块生成射野角度,BAO优化参数设定:共面照射;最小射野数和最大射野数均为5;初始射野数为36,最小射野间隔角度为10°;最大邻近射野角度变化为180°,其他参数为默认值。3种计划调强优化参数设定一致:PTV最大剂量小于107%处方剂量,最小剂量大于95%处方剂量;肝脏剂量 $V_5 \leq 45\%$ 、 $V_{10} \leq 30\%$ 、 $V_{20} \leq 20\%$;双肾剂量 $V_5 \leq 25\%$ 、 $V_{10} \leq 20\%$ 、 $V_{20} \leq 10\%$;小肠剂量 $V_5 \leq 40\%$ 、 $V_{20} \leq 30\%$ 、 $V_{30} \leq 20\%$;胃 $V_{30} \leq 60\%$ 、 $V_{40} \leq 40\%$;脊髓最大剂量 ≤ 40 Gy;双肺剂量 $V_5 \leq 40\%$ 、 $V_{20} \leq 20\%$;心脏 $V_{40} \leq 25\%$ 。

计划评估分别比较EGA和BAO计划以及MBS与BAO计划的治疗跳数(MU)和PTV的 $D_{50\%}$ 、 $V_{100\%}$ 、 $D_{2\%}$ 、 $D_{98\%}$,3组计划均按100%处方剂量包括95%靶区体积归一。适形度指数(Conformity Index, CI)以 $CI = V_{T,ref}/V_T \times V_{T,ref}/V_{ref}$ 表示,其中 V_T 为靶区体积, $V_{T,ref}$ 为处方等剂量面包裹的靶区体积, V_{ref} 为处方等剂量面包裹的总体积。剂量均匀性指数(Homogeneity Index, HI)以 $HI = (D_{2\%} - D_{98\%})/D_{50\%}$ 表示^[11]。危及器官:比较肝脏 D_{mean} 、 V_{10} 、 V_{20} 、 V_{30} ;双肾 D_{mean} 、 V_5 、 V_{10} 、 V_{20} ;小肠 D_{mean} 、 V_5 、 V_{10} 、 V_{20} ;胃 D_{mean} 、 V_{10} 、 V_{20} 、 V_{30} 、 V_{40} ;脊髓最大剂量;双肺 D_{mean} ;心脏 D_{mean} 、 V_{30} 、 V_{40} ;Body-PTV体积(扫描体积减去PTV体积) D_{mean} 、 V_5 、 V_{10} 、 V_{20} 、 V_{30} 、 V_{40} 。采用SPSS 19.0统计分析软件对以上剂量学数据进行配对 t 检验,以 $P < 0.05$ 为差异有统计学意义。

2 结果

剂量学检验结果显示(表1、表2),EGA与BAO计划比较:(1)PTV剂量学参数差异均无统计学意义($P > 0.05$);(2)危及器官:肝脏 D_{mean} 、 V_{10} 、 V_{20} ;双肾 D_{mean} 、 V_{10} 、 V_{15} 、 V_{20} ;胃 D_{mean} 、 V_{10} ;双肺 D_{mean} 、 V_{10} ;Body-PTV D_{mean} 、 V_5 、 V_{10} 差异有统计学意义($P < 0.05$),BAO组优于EGA组;(3)MU差异无统计学意义($P > 0.05$)。

MBS与BAO计划比较:(1)PTV剂量学参数差异均无统计学意义($P > 0.05$);(2)危及器官:双肾 V_{15} 、 V_{20} ,胃 D_{mean} 、 V_{10} 差异有统计学意义($P < 0.05$),BAO组优于MBS组;(3)MU差异无统计学意义($P > 0.05$)。

不同计划的射野角度差异如图1所示,BAO与EGA的射野角度差异要大于BAO与MBS计划间的差异,不同患者BAO的射野角度分布也存在明显差别。

3 讨论

国内外文献报道对于头颈部肿瘤计划在达到相

表 1 PTV 剂量学数据比较 ($\bar{x}\pm s$)Tab.1 Dosimetric data comparison of PTV between EGA, MBS and BAO plans (*Mean±SD*)

Parameber	EGA	MBS	BAO	Diff (%) ^a	<i>P</i> ^a	Diff (%) ^b	<i>P</i> ^b
D _{50%} (Gy)	46.98±1.27	46.92±1.09	46.97±1.12	0.02	0.979	-0.10	0.675
V _{100%} (%)	94.93±0.01	94.92±0.01	94.90±0.01	0.03	0.268	0.02	0.310
D _{2%} (Gy)	48.31±1.57	48.36±1.29	48.47±1.42	-0.33	0.618	-0.23	0.678
D _{98%} (Gy)	44.28±0.18	44.29±0.28	44.33±0.43	-0.11	0.653	-0.09	0.604
CI	1.20±0.11	1.22±0.08	1.23±0.09	-2.50	0.266	-0.82	0.751
HI	0.85±0.03	0.86±0.03	0.87±0.03	-2.35	0.774	-1.16	0.858

Note: PTV: Planning target volume; EGA: Equally- spaced gantry angles; MBS: Manual beam angle selection; BAO: Beam angle optimization; CI: Conformity index; HI: Homogeneity index. a: Comparing EGA plans with BAO plans; b: Comparing MBS plans with BAO plans

表 2 MU 和危及器官剂量学数据比较 ($\bar{x}\pm s$)Tab.2 Comparison of MU and dosimetric data of OARs between EGA, MBS and BAO plans (*Mean±SD*)

Parameber	EGA	MBS	BAO	Diff (%) ^a	<i>P</i> ^a	Diff (%) ^b	<i>P</i> ^b
MU	745.33±80.08	703.67±74.42	695.00±63.71	6.75	0.832	1.23	0.887
Liver							
D _{mean} (Gy)	16.08±2.54	12.93±2.76	12.58±2.52	21.77	0.003	2.71	0.161
V ₁₀ (%)	55.58±10.60	39.84±8.20	37.97±9.89	31.68	0.004	4.69	0.218
V ₂₀ (%)	40.93±9.17	27.50±7.88	25.43±6.24	37.87	0.006	7.53	0.283
V ₃₀ (%)	13.14±4.21	12.76±3.84	13.05±5.15	0.68	0.881	-2.27	0.688
Kidneys							
D _{mean} (Gy)	6.74±2.81	5.63±1.16	5.13±1.94	23.83	0.039	8.80	0.090
V ₅ (%)	33.26±12.53	32.83±15.16	32.09±15.57	3.53	0.855	2.27	0.498
V ₁₀ (%)	23.74±8.23	16.82±8.07	16.26±6.53	31.51	0.024	3.36	0.355
V ₁₅ (%)	16.73±4.96	10.39±5.75	6.59±3.30	60.60	0.026	36.54	0.032
V ₂₀ (%)	12.12±4.60	6.39±2.74	3.58±1.15	70.45	0.018	43.97	0.034
Stomach							
D _{mean} (Gy)	26.34±6.22	25.43±6.67	24.43±6.17	7.25	0.025	3.93	0.035
V ₁₀ (%)	83.27±19.14	82.48±18.57	80.12±20.03	3.78	0.027	2.86	0.038
V ₂₀ (%)	72.52±14.99	67.33±14.40	60.08±14.03	17.15	0.108	10.77	0.073
V ₃₀ (%)	43.30±12.13	39.37±12.79	40.97±12.74	5.38	0.560	-4.06	0.391
V ₄₀ (%)	17.57±8.70	18.34±12.55	15.67±8.07	10.81	0.453	14.55	0.574
Intestine							
D _{mean} (Gy)	15.30±3.88	13.34±3.08	13.06±2.91	14.64	0.176	2.10	0.615
V ₁₀ (%)	56.85±18.92	49.06±12.45	46.40±8.13	18.38	0.130	5.42	0.488
V ₂₀ (%)	40.90±15.40	28.84±12.82	24.67±7.84	39.68	0.172	14.46	0.251
V ₃₀ (%)	8.79±3.50	9.71±4.49	10.49±5.51	-19.34	0.449	-8.03	0.772
Heart							
D _{mean} (Gy)	6.80±2.87	7.29±3.32	7.44±3.36	-9.41	0.157	-2.06	0.606
V ₃₀ (%)	4.48±2.84	6.16±2.90	6.27±3.08	-39.96	0.137	-1.79	0.924
V ₄₀ (%)	2.38±1.53	2.66±1.63	2.85±1.84	-19.75	0.230	-7.14	0.604
Cord_PRV							
D _{max} (Gy)	35.00±9.39	32.82±3.60	31.85±5.70	9.00	0.522	2.96	0.655
Lung							
D _{mean} (Gy)	3.91±2.40	3.61±2.30	3.51±2.11	10.23	0.024	2.77	0.340
V ₅ (%)	19.22±10.93	16.25±7.00	16.11±7.37	16.18	0.108	0.86	0.732
V ₁₀ (%)	11.99±6.92	10.34±5.91	9.57±5.02	20.18	0.035	7.45	0.186
V ₂₀ (%)	5.38±2.89	5.71±3.52	4.98±2.21	7.43	0.605	12.78	0.439
Body-PTV							
D _{mean} (Gy)	5.68±1.82	5.32±1.75	5.25±1.69	7.57	0.006	1.32	0.170
V ₅ (%)	26.80±7.60	24.44±7.09	24.05±6.99	10.26	0.005	1.60	0.160
V ₁₀ (%)	19.59±5.82	17.81±5.29	17.20±4.78	12.20	0.010	3.43	0.083
V ₂₀ (%)	13.61±5.25	12.48±4.46	11.45±3.75	15.87	0.076	8.25	0.056
V ₃₀ (%)	5.58±2.40	5.85±2.29	6.08±2.69	-8.96	0.237	-3.93	0.417
V ₄₀ (%)	3.28±1.28	3.35±1.25	3.31±1.28	-0.91	0.528	1.19	0.342

Note: MU: Monitor unit; OARs: Organs at risk. a: Comparing EGA plans with BAO plans; b: Comparing MBS plans with BAO plans

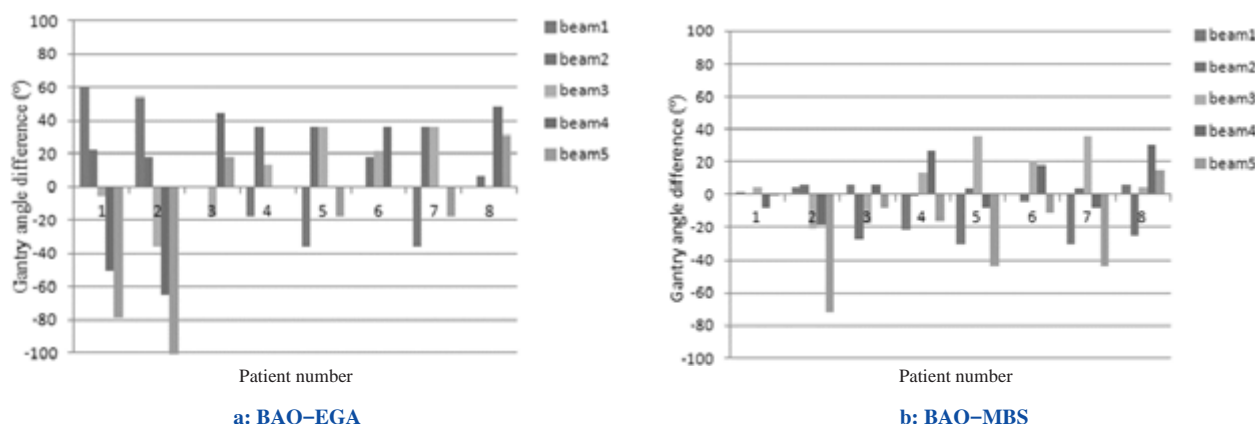


图1 BAO与EGA、BAO与MBS计划射野机架角差值

Fig.1 Gantry angle differences between BAO plans and EGA plans, MBS plans

同评分时,BAO布野需要的射野数更少^[5]。对于肺癌计划BAO使用5野或7野可以获得与9野均分布野相似的计划质量,提高了治疗效率^[6]。在前列腺癌放疗中可以更好地保护膀胱和直肠,减少MU、子野数目和全身剂量^[7]。但也有文献显示BAO对于胸中段食管癌计划的剂量学改进较胸上段食管癌计划更为明显,对于宫颈癌使用9野均分布野,不论在靶区适形度、均匀性还是在降低危及器官受照剂量方面均优于BAO计划^[10]。因此对于不同部位、体积的肿瘤靶区,使用BAO得到的剂量学结果存在一定差异,有必要对某一类型的肿瘤进行具体的研究。

本文的剂量学数据显示BAO与EGA计划比较,在不降低靶区剂量均匀性和适形度的前提下可以明显降低肝脏 D_{mean} 、 V_{10} 、 V_{20} ,双肾 D_{mean} 、 V_{10} 、 V_{15} 、 V_{20} ,胃 D_{mean} 、 V_{10} ,双肺 D_{mean} 、 V_{10} ,Body-PTV D_{mean} 、 V_5 、 V_{10} 。表明BAO计划相对EGA有着明显的剂量学优势,可以减轻患者的副反应^[12-13]。胃癌放疗靶区一般不处于患者体内中心位置,并且四周有肝脏、双肾、小肠等危及器官包绕,空间位置关系比较复杂。使用均匀布野的计划没有考虑靶区和危及器官的相对空间位置关系和患者个体的解剖结构的位置体积差异,不足以很好地保护危及器官。BAO与MBS计划比较,保证靶区适形度和均匀性不变的情况下,可以明显降低双肾的 V_{15} 、 V_{20} ,胃 D_{mean} 、 V_{10} 。表明人工选择射野角度的计划一定程度改善了剂量学分布,但BAO在降低危及器官受量仍然占有优势。人工布野极大地依赖于计划设计者的经验,虽然相对于均匀布野计划可以提高计划的剂量学分布,但通常难以一次性获取较优的布野方式,需要以试错法不断调整射野角度以改善剂量分布^[7]。因此要花费更多的计划时

间,特别是当计划较多物理师工作状态下降时,人工布野的计划可能耗费更多时间并且计划质量出现降低,相比较BAO计划则不存在这些问题,完全依赖于计算机软硬件的工作能力。BAO计划分别与EGA和MBS计划的射野角度差值分布也体现了患者间BAO结果的个体差异,BAO可以给出更适合某个患者的射野分布。

综上所述。在胃癌术后放疗计划设计中,使用BAO布野更好地保护了危及器官,存在进一步提升靶区剂量的可能,是一种有效的计划设计方法。

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