应用两种三维探测器阵列进行螺旋断层调强放疗计划剂量验证

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【摘 要】**目的**:研究分别采用 Delta⁴ 和 ArcCheck 三维探测器阵列对螺旋断层放疗系统(TOMO)的调强计划实施剂量验证的异同。**方法**:分别采用 ScandiDos 公司 Delta⁴ 三维半导体探测器阵列和 Sun Nuclear 公司 ArcCheck 三维半导体探测器阵列对 10 例患者的 TOMO 调强放疗计划实施验证。通过 TOMO 系统 MVCT 成像和配准消除床面沉降的影响,确保实现两种三维探测器阵列的精确摆位。实施治疗质量保证(Delivery Quality Assurance, DQA)计划照射后将探测器阵列测量获得的平面剂量分布与 TOMO 计划系统模体计划计算获得的平面剂量分布进行比较。采用 Gamma 分析方法,选择多个不同的剂量标准分析评估验证情况。**结果**:阈值水平(Threshold, TH)分别为 5%、10%、20%、70%、90%时,采用 3% /2 mm、3%/3 mm、3%/4 mm、3%/5 mm 四种不同剂量偏差/吻合距离剂量标准,γ≤1 的平均通过率均超过 94.1%,测量所得剂量分布与计算结果在相应平面的几何分布均呈现出良好的一致性。**结论**:两种三维探测器阵列各具特点,用于 TOMO 调强放疗计划验证能够获得令人满意的结果。

【关键词】螺旋断层放疗; 三维探测器阵列; 调强放疗; 剂量验证; 质量保证
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Dose Verification of Helical Tomotherapy in the Intensity Modulated Planning with Three-dimensional Semiconductor Arrays Delta⁴ and ArcCheck

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Abstract: **Objective** To compare the Delta⁴ three dimensional detector array with the ArcCheck detector array in dose verification of tomotherapy (TOMO) intensity modulated planning. **Methods** 10 patients were selected to verify dose distribution in the TOMO plan with the Delta⁴ and ArcCheck detector arrays. The precise setup of detector arrays was insured by MVCT imaging. The measured dose distribution on the corresponding planes were compared with those calculated by the treatment planning system (TPS) after the implementation of delivery quality assurance (DQA) plan. Several different dose distribution assessments were chosen to verify the results made by Gamma analysis. **Results** 4 different doses 3%/2 mm, 3%/3 mm, 3%/4 mm, 3%/5 mm were used when the thresholds were TH_5, TH_{10}, TH_{20}, TH_{70}, TH_{90}. The mean passing rates with γ parameter ≤1 were all above 94.1%. The dose distribution measured by these two kinds of three dimensional detector arrays combining corresponding phantoms was well consistent with which was calculated by TPS. **Conclusion** Three dimensional detector arrays both the Delta⁴ and ArcCheck with corresponding phantoms can get satisfying results when used in dose verification of TOMO plan.

Key words: tomotherapy; three dimensional detector array; IMRT; dose verification; quality assurance

前 言

螺旋断层放疗系统 (TOMO)是一种在 CT 图像引导下,以逆向调强放疗(Intensity Modulated Radiotherapy, IMRT)为主的当代最先进的放疗设备之一。凭借其薄层照射理念,二元气动多叶光栅(Binary MLC),实时影像引导放疗 (Image Guided Radiotherapy, I-GRT), 独创的自适应放疗 (Adaptive Radiotherapy, ART)计划等创新技术,已成为现代影像引导放疗的代表性设备, 突破了传统肿瘤放疗技术的诸多局限,将当代影像引导逆向调强技术推进到一个前所未有的新境界[1-4]。目前,除传统的胶片验证方法外,二维或

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三维阵列探测器已广泛应用于 TOMO 的质量保证(Quality Assurance, QA)过程中[5-18]。笔者利用 Delta4(ScandiDos,Sweden)和 ArcCheck (SunNuclear,USA)三维探测器阵列联合各自相应的配套模体对 10 例患者的 TOMO 调强放疗计划进行剂量验证，探讨应用这两种三维探测器阵列进行 TOMO 临床 QA 的可行性及其差异。

1 材料与方法

1.1 Delta⁴ 探测器阵列

Delta⁴ 探测器阵列由放置在 22 cm×40 cm 圆柱型模体中呈正交排列的主板阵列和翼板阵列构成,后者又分为翼板 1 和翼板 2。共有 1069 个敏感面积为 0.78 mm² 的 P 型圆柱型半导体探头,这些探头分布在 20 cm×20 cm 的区域内,中心 6 cm×6 cm 区域内探头间隔 5 mm,中心区域以外的区域探头间隔为 10 mm。利用这两个正交排列的探测器平面可以实现对所有入射角度的射线束截面的剂量测量。使用 Delta⁴ 之前,需在常规加速器对其进行相对剂量刻度和方向性刻度,还要在 TOMO 加速器进行绝对剂量刻度。

1.2 ArcCheck 探测器阵列

在 21 cm 长圆柱型模体上分布有 1386 个敏感体积为 0.64 mm² 的 P 型半导体探头，探头间距为 10 mm,物理深度 29 mm,等效固体水深度 33 mm,信号采集时间间隔 50 ms。与 Delta⁴ 类似,使用 ArcCheck 之前,需在常规加速器对其进行相对剂量刻度和方向性刻度,还要在 TOMO 加速器进行绝对剂量刻度。

1.3 模体调强放疗计划的设计及验证测量

选取经主任医师确认的 10 例患者的调强放疗计划,包括头颈部肿瘤 4 例,其中鼻咽癌 1 例,喉癌 2 例,舌根癌 1 例;胸部肿瘤 3 例,其中食管癌 2 例,肺癌 1 例;腹部肿瘤 3 例,均为直肠癌。分别选取 Delta⁴ 探测器阵列与 ArcCheck 阵列及模体组合作为 DQA 验证模体,根据验证模体图像上的 3 个标记点调节好红色摆位激光灯的位置,从而确定其位置。选择与患者治疗计划设计时相对应的栅格矩阵计算模体 DQA 计划的剂量分布。测量时,从 TOMO 的数据服务器中调用 10 例患者 DQA 验证模体计划。将 Delta⁴ 和 ArcCheck 探测器阵列模体组合置于诊疗床按红色摆位激光灯指示进行摆位，采用 MVCT 进行精确摆位校正后按计划条件实施照射。

1.4 评估方法

测量完毕后，应用 Gamma 分析法对 Delta⁴ 和 ArcCheck 探测器阵列的测量结果与 TOMO 治疗计划系统 DQA 模体计划的计算结果进行比较。Gamma 分析剂量标准分别选择为剂量误差(Dose Difference, DD)3%/ 吻合距离 (Distance-to-Agreement, DTA)2 mm、3%/3 mm、3%/4 mm、3%/5 mm,阈值(Threshold)分别设定为 TH5、TH10、TH20、TH70, TH90。TH5 表示只有那些点剂量超过最大剂量 5%的点才会在 Gamma 分析中予以考虑,余类同。

尽管 ICRU 83 号报告[19]建议可将治疗计划的接受标准放宽至 5%/5 mm,但我们在日常临床工作中仍遵循文献所建议的 DQA 计划接受标准 [20-21]: 3% /3 mm 条件下 γ 通过率达 90%以上即认为患者计划是可接受的。

2 结果

采用 Gamma 分析方法对 10 例患者的调强计划剂量验证分析结果表 1。按照上述接受标准,所选 10 例患者调强计划均符合要求,且在所有剂量标准条件下应用两种探测器阵列的通过率差异均无显著性意义(P>0.05)。

3 讨论

TOMO 作为一种新的动态旋转调强照射技术,其治疗计划设计和照射实施方式与常规加速器调强放疗相比存在较大差别。本研究采用 Delta⁴ 与 Arc-

表 1 应用 Delta⁴ 和 ArcCheck 探测器阵列对 10 例患者计划验证的 Gamma 通过率(%)

Tab.1 Gamma Passing Rate (%) of 10 Patients Using Delta⁴ and ArcCheck Detectors Arrays

No.	3%/2 mm					3%/3 mm				
	TH5	TH10	TH20	Th70	TH90	TH5	TH10	TH20	TH70	TH90
1	92.9(98.1)	92.7(98.1)	93.6(98.0)	95.1(97.5)	96.5(97.1)	97.1(98.3)	97.1(98.3)	97.6(98.3)	97.5(97.8)	98.7(97.1)
2	91.9(96.2)	91.6(96.2)	91.3(96.2)	88.6(92.6)	88.6(95.8)	97.4(98.3)	97.3(98.3)	97.3(98.2)	96.4(96.9)	96.3(97.2)
3	97.1(95.2)	96.7(93.5)	96.5(93.3)	95.4(92.8)	94.8(100)	99.0(97.5)	98.9(96.6)	98.8(96.5)	98.5(95.5)	98.3(100)
4	96.4(93.3)	97.5(91.9)	98.9(91.4)	98.2(92.7)	97.8(93.2)	97.6(96.6)	98.8(95.9)	99.5(95.6)	99.3(94.8)	99.1(95.4)
5	94.9(96.3)	94.7(95.8)	94.4(95.6)	92.0(97.4)	92.1(98.9)	97.2(98.6)	97.1(98.4)	96.9(98.3)	95.5(98.2)	95.4(99.7)
6	95.1(88.1)	95.3(87.1)	96.1(86.8)	98.2(90.5)	100(100)	97.4(92.1)	97.6(91.5)	98.4(91.3)	99.1(96.1)	100(100)
7	97.5(98.1)	97.1(97.9)	96.8(97.7)	95.8(97.9)	97.8(93.5)	99.5(98.8)	99.4(98.7)	99.3(98.6)	99.6(98.6)	99.7(97.1)
8	90.1(88.4)	89.6(88.2)	89.3(88.4)	91.2(84.1)	93.0(92.7)	94.2(93.3)	93.9(93.2)	93.7(93.0)	94.3(86.7)	94.8(94.0)
9	96.3(99.0)	95.8(98.8)	95.6(98.7)	94.9(97.3)	95.7(97.6)	98.0(99.0)	97.7(98.8)	97.6(98.7)	97.3(98.3)	97.6(97.7)
10	99.5(98.8)	99.5(98.8)	99.5(98.7)	99.5(98.3)	99.8(100)	99.8(99.4)	99.8(99.3)	99.8(99.3)	99.8(98.8)	100(100)
P value	0.987	0.767	0.644	0.616	0.355	0.419	0.279	0.222	0.137	0.817

续表 1

No.	3%/4 mm					3%/5 mm				
	TH5	TH10	TH20	TH70	TH90	TH5	TH10	TH20	TH70	Th90
1	98.7(98.5)	98.6(98.5)	98.8(98.5)	98.1(97.8)	98.7(97.1)	99.6(98.6)	99.6(98.6)	99.6(98.7)	98.9(97.8)	98.7(97.1)
2	98.4(99.3)	98.3(99.3)	98.3(99.3)	97.9(98.8)	97.6(99.3)	98.5(99.8)	98.4(99.8)	98.4(99.8)	97.9(99.3)	97.1(99.3)
3	99.4(98.4)	99.3(97.9)	99.3(97.8)	99.1(97.1)	99.0(100)	99.5(98.9)	99.4(98.6)	99.4(98.5)	99.3(98.0)	99.2(100)
4	98.4(97.8)	99.7(97.4)	99.9(97.2)	99.8(96.4)	99.8(97.9)	98.6(98.4)	99.9(98.1)	99.9(97.9)	99.8(97.4)	99.8(98.7)
5	97.8(98.8)	97.8(98.6)	97.7(98.6)	96.7(98.4)	96.3(100)	98.5(99.1)	98.5(98.9)	98.5(98.9)	97.7(98.8)	97.5(100)
6	99.1(95.2)	99.2(94.8)	99.7(94.7)	99.3(98.8)	100(100)	99.2(97.5)	99.3(97.1)	99.7(97.1)	99.3(99.4)	100(100)
7	99.9(98.9)	99.9(98.8)	99.9(98.8)	99.8(98.6)	99.7(97.1)	100(98.9)	100(98.8)	100(98.8)	100(98.6)	100(97.1)
8	96.6(95.2)	96.4(95.1)	96.3(95.0)	96.5(89.7)	96.4(95.4)	98.2(96.1)	98.1(96.1)	98.0(95.9)	97.6(91.3)	97.2(96.7)
9	99.1(99.3)	99.0(99.1)	99.0(99.0)	98.9(98.6)	98.7(98.3)	99.4(99.4)	99.3(99.2)	99.2(99.2)	99.1(99.7)	98.9(99.5)
10	99.8(99.8)	99.8(99.8)	99.8(99.8)	99.8(99.3)	100(100)	99.9(99.9)	99.9(99.8)	99.9(99.8)	100(99.6)	100(100)
P value	0.210	0.124	0.114	0.138	0.857	0.177	0.072	0.073	0.202	1.000

Check 三维探测器及相应模体组合对 10 例患者的 TOMO 调强放疗计划进行了剂量验证,在多种不同剂量标准条件下,测量结果与计算结果均显示出较好的一致性,$\gamma \leqslant 1$ 的平均通过率均超过 94.1%。Delta^4 和 ArcCheck 采用的 P 型圆柱型半导体探头具有各向同性的物理特性,无角度依赖性,可实现 360^o 范围内任意角度的精确测量。需要指出的是,本研究中无论使用 Delta^4 或 ArcCheck 阵列,在 3%/2 mm 剂量标准条件下均有通过率低于 90%的情况出现。原因可能在于,与胶片剂量仪相比,这两种三维探测器阵列的空间分辨率均较低(≥5 mm),一旦肿瘤靶区的边缘部分落入探测器敏感区, 受剂量跌落和散射线影响较大,可导致计划剂量与测量剂量差别明显造成通过率较低。尽管如此,Delta^4 和 ArcCheck 探测器阵列的操作软件简便快捷, 较之使用胶片验证法能够节省约 20 min~30 min 的时间,通过在治疗靶区内测量 X、Y、Z 三个方向的实际剂量梯度,这两种探测器均实现了真正的三维剂量验证解决方案。

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