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医学放射物理

实验细胞直线加速器照射方法与剂量学探讨

李建锋[1],黄顺平[2]
1.重庆大学附属肿瘤医院/重庆市肿瘤研究所/重庆市肿瘤医院，重庆 400030；2.重庆医科大学附属第二医院，重庆 400010

【摘 要】目的：探讨不同深度、不同照射方式及空腔效应在离体细胞照射中的影响，为选择合适的照射方式以减少照射剂量不确定性提供参考。**方法：**培养皿中分别加入不同深度的培养液，上盖1 cm厚补偿物，下加4 cm固体水，模拟机架0°照射无旁向散射时不同深度的培养液对细胞剂量的影响。获取此摆位情况下的CT图像；培养皿置于一注有等高培养液大培养皿中，同前加入补偿物和固体水，模拟机架0°照射时增加旁向散射对细胞剂量影响，同样获取CT图像。将前一步的补偿物和散射体，改为上加4 cm厚固体水，下放1 cm厚有机玻璃体膜板，获取此摆位情况下的CT图像，模拟机架180°照射时增加旁向散射对细胞剂量影响；去掉外周培养皿，模拟机架180°照射时无旁向散射对细胞剂量影响。基于获取的CT图像做计划，分析剂量分布，剂量分布结果均以相对剂量(%)表述。**结果：**2.5、5.0、7.2 mm深度处培养皿底壁的剂量最大偏差分别为5.5%、4.2%、6.5%。机架为0°照射无旁向散射，剂量最大偏差为14.7%，平均剂量为96.6%；增加旁向散射后剂量最大偏差4.9%，平均剂量97.1%。机架为180°照射无旁向散射，剂量最大偏差为10.5%，平均剂量为98.6%；增加旁向散射后最大剂量偏差3.1%，平均剂量99.1%。**结论：**180°机架照射比0°照射受照细胞剂量偏差更小且均匀性更好。增加旁向散射可以明显改善外侧培养液和培养皿壁部的剂量分布。

【关键词】直线加速器；细胞照射；旁向散射；剂量学
【中图分类号】R811.5 **【文献标志码】**A **【文章编号】**1005-202X(2017)12-1211-05

Irradiation method of experimental cell on linear accelerator and dosimetry study

LI Jianfeng[1], HUANG Shunping[2]
1. Chongqing University Cancer Hospital/Chongqing Cancer Institute/Chongqing Cancer Hospital, Chongqing 400030, China; 2. the Second Affiliated Hospital of Chongqing Medical University, Chongqing 400010, China

Abstract: Objective To explore the effect of culture medium of different depths, irradiation methods and cavity effect on the irradiation of experimental cell, and to minimize the uncertainty of exposure dose by providing reference for choosing the optimal irradiation method. **Methods** The culture medium of different depths was added into different culture dishes, with 1 cm of compensation on the cover and 4 cm of solid water on the bottom, and then, the irradiation at a gantry angle of 0° without side scattering was carried out for investigating the effect of the culture medium of different depths on the cell irradiation and obtaining the CT image. After the culture dish was placed into a larger culture dish with the same depth of culture medium to simulate the side scattering and the compensation and solid water were added as in previous treatment, the effect of the irradiation at a gantry angle of 0° with side scattering on cell irradiation was discussed and the CT image was obtained. The effect of the irradiation at a gantry angle of 180° with side scattering on cell irradiation was analyzed and CT image was obtained by replacing the previous compensation and solid water with 4 cm of solid water on the cover and 1 cm of organic vitreous membrane on the bottom. After removing the peripheral culture medium, we analyzed the effect of the irradiation a gantry angle of 180° without side scattering on cell irradiation. Based on those obtained CT images, treatment plans were designed and the dose distributions which were expressed in relative doses (%) were compared. **Results** The maximum dose deviation was 5.5%, 4.2%, and 6.5% for 2.5, 5.0, and 7.2 mm of culture medium, respectively. The maximum dose deviation and mean dose were 14.7% and 96.6% for the irradiation at a gantry angle of 0°without side scattering, and 4.9% and 97.1% for that with side scattering. Furthermore, the maximum dose deviation and mean dose were 10.5% and 98.6% for the irradiation at a gantry angle of 180° without side scattering, and 3.1% and 99.1% for that with side scattering. **Conclusion** For experimental cell irradiation, irradiation at a gantry angle of 180° has a smaller dose deviation and a better homogeneity than the irradiation a gantry angle of 0°, and adding side

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【作者简介】李建锋，技师，研究方向：肿瘤放疗技术，E-mail: 240735257@qq.com
【通信作者】黄顺平，主管技师，研究方向：放射性肠炎的发病因素，E-mail: 410124615@qq.com

scattering can dramatically improve the dose distribution of lateral culture medium and adherent culture.
Keywords: linear accelerator; cell irradiation; side scattering; dosimetry

前 言

随着肿瘤放疗技术的不断发展，放射生物的研究也不断深入[1-2]。对于放射生物的研究通常会涉及到离体细胞照射[3-4]。在对实验细胞的照射中，准确的剂量是实验数据真实的保障。不同的照射方法对实验细胞所受的照射剂量有着较大的差异，也影响着实验结果的准确性[5-7]。选择正确的照射方法可以减少细胞所受照射剂量的不确定性，提高结论的准确性与可靠性[8-10]。

王皓等[7]研究了单次（400 cGy/min）、分次（2 Gy/次/天，400 cGy/min）和持续低剂量率（^{125}I粒子，2.77 cGy/h）照射后对直肠癌CL187细胞生物学效应的影响，他们发现：^{125}I粒子持续低剂量率照射对结直肠癌CL187细胞杀伤作用更强。刘瑞风等[11]研究了不同照射方式对小鼠γ射线最小致死量的研究，得出鼠盒上有4.5 mm厚的盖板进行照射是对小鼠γ射线照射的较好方式，最小致死量为10.0 Gy。

先前报道的研究均是通过实际照射离体细胞等实验方式，分析细胞生物学效应等，以期获取较为合适的照射方式[12-16]；然而，这并不能进一步地确保实际照射时剂量的准确性。研究的目的是模拟直线加速器照射贴壁生长和悬浮生长细胞实验过程，探讨不同深度、培养皿内的空腔和培养皿侧壁的旁向散射以及不同照射方向对实验细胞所受剂量的影响。通过不同照射方法剂量学的比较，选择合适的照射方法，减少细胞所受照射剂量的不确定性。

1 材料与方法

培养皿中分别加5、10、15 mL的培养液，液面深度分别为2.5、5.0、7.2 mm，上盖1 cm厚补偿物，背面加4 cm固体水为散射体（图1）。模拟机架0°照射无旁向散射时不同深度的培养液对细胞剂量的影响。

图1 0°照射时玻璃培养皿周围建成材料实物图

Fig.1 Build-up around the glass culture dish at a gantry angle of 0°

培养皿置于一注有等高培养液大培养皿中模拟增加旁向散射体（图2），上盖1 cm厚补偿物，下加4 cm固体水为散射体，模拟机架0°照射时增加旁向散射对悬浮生长细胞外侧细胞剂量的影响。

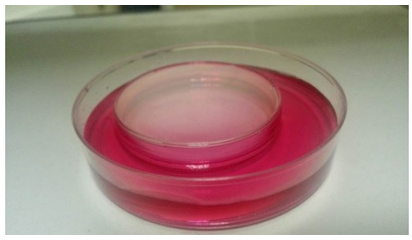


图2 玻璃培养皿外增加旁向散射体

Fig.2 Side scattering outside the glass culture dish

培养皿置于一注有等高培养液大培养皿中。放在1 cm厚有机玻璃体膜板上，上面加盖4 cm厚固体水作背向散射，模拟加旁向散射体后180°照射（图3）。

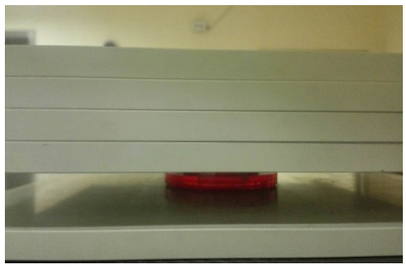


图3 180°照射时建成材料的放置

Fig.3 Build-up around the culture dish in the irradiation at a gantry angle of 180°

去掉外侧培养皿，模拟机架180°照射时无旁向散射对细胞剂量影响，建成材料与图3相同。

在CT模拟机上对培养皿的各种放置方法进行CT扫描后导入计划系统（Treatment Planning System, TPS）。模拟给予6 MV能量X线，源皮距（Source Surface Distance, SSD）设置为100 cm，射野10 cm×10 cm、100 MU照射。模拟贴壁生长细胞和悬浮生长细胞的区域勾画不同的CTV用于分析（图4和图5）。

设备介绍：① 玻璃培养皿，培养液为RPMI1640培养基、10%胎牛血清、青霉素100 U/mL和链霉素0.1 mg/mL（杭州四季青公司）；② 飞利浦放疗专用大孔径螺旋CT（Philips Brilliance™ Big Bore CT）：

85 cm孔径,16层/360°螺旋采集;③美国Varian公司网络系统VARIS,医生工作站Somovision,Varian Eclipse TPS。

2 结 果

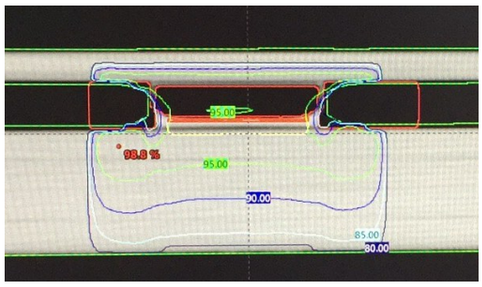
2.1 培养液不同深度对细胞照射时剂量分布的影响

剂量分布结果均以相对剂量(%)表述。培养液深度的改变对细胞在照射中所接受的剂量有影响。2.5、5.0、7.2 mm深度处培养皿底壁的剂量最大偏差分别为5.5%、4.2%、6.5%,见表1和图4。

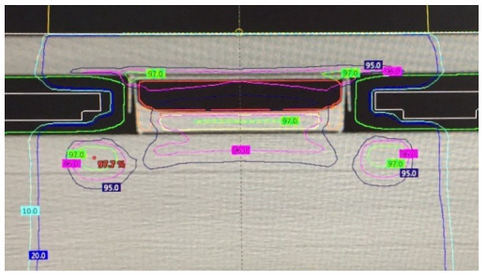
表1 不同液面深度射野中心轴细胞受照剂量

Tab.1 Irradiated dose to cell at the center axis of the field in different depths of culture medium

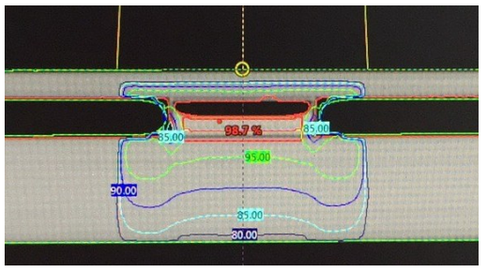
Depth /mm	Volume/mL	D_{max}/%	D_{min}/%
2.5	5	97.3	94.4
5.0	10	97.3	95.8
7.2	15	97.6	93.5



a: At a depth of 2.5 mm



b: At a depth of 5.0 mm



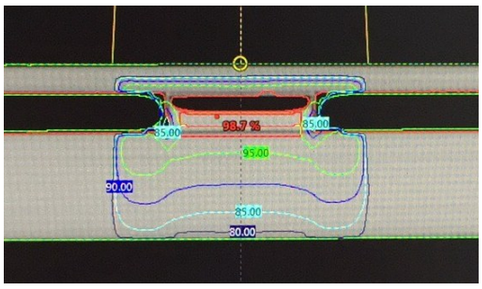
c: At a depth of 7.2 mm

图4 不同深度培养液的剂量分布

Fig.4 Dose distributions at different depths of culture medium

2.2 空腔效应对细胞照射时剂量分布的影响

剂量分布结果均以相对剂量(%)表述。10 mL培养液(5.0 mm深度)不同照射角度和方法对培养液受照剂量的影响。机架为0°照射无旁向散射时,剂量最大偏差为14.7%,平均剂量为96.6%;增加旁向散射后剂量最大偏差4.9%,平均剂量97.1%,见图5和表2。机架为180°照射无旁向散射,剂量最大偏差为10.5%,平均剂量为98.6%;增加旁向散射后最大剂量偏差3.1%,平均剂量99.1%,见表2和图6。180°机架照射比0°照射受照细胞剂量偏差更小且均匀性更好。



a: Without side scattering

b: With side scattering

图5 10 mL(5 mm深度)培养液机架0°照射剂量分布

Fig.5 Dose distribution at a gantry angle of 0° and culture medium of 10 mL (5 mm depths)

2.3 旁向散射对细胞照射时剂量分布的影响

实验发现,旁向散射对于贴底壁生长的细胞没有太大影响,而对于侧壁和悬浮生长细胞剂量有较大影响。由图7可见,增加旁向散射可以明显改善外侧培养液和培养皿壁部的剂量分布。

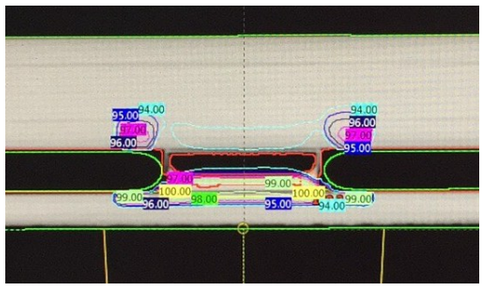
3 讨 论

肿瘤的细胞基础实验需要对所培养或采集的细胞进行照射,目前一般采用直线加速器6 MV X线照射,SSD设置为100 cm,在其射线入射方向加一定厚度的补偿物以作剂量建成[17-20]。目前大部分的研究都是通过细胞实际照射得到最佳的照射方式,少有对细胞照射方法剂量学的研究。本研究通过基于CT图像,利用TPS制定照射计划,分析和比较剂量分布

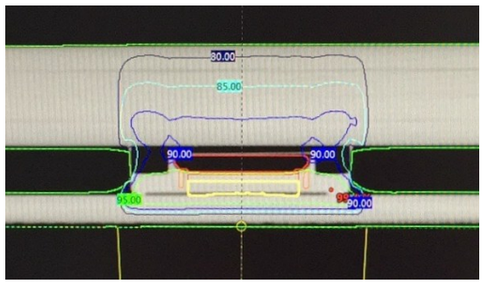
表2 10 mL(5 mm深度)培养液不同照射角度和有无旁向散射细胞受照射的剂量(%)

Tab.2 Irradiated dose to cells at gantry of different angles and culture medium of 10 mL (5 mm depths) with/without side scattering(%)

No scattering at a gantry of 0°			Scattering at a gantry of 0°			No scattering at a gantry of 180°			Scattering at a gantry of 180°		
D_{max}	D_{min}	D_{mean}	D_{max}	D_{min}	D_{mean}	D_{max}	D_{min}	D_{mean}	D_{max}	D_{min}	D_{mean}
99.6	85.3	96.6	99.6	95.1	97.1	99.8	89.5	98.6	99.9	96.9	99.1



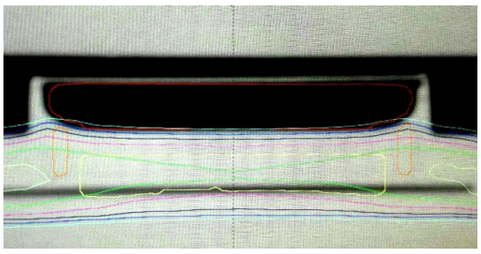
a: Without side scattering



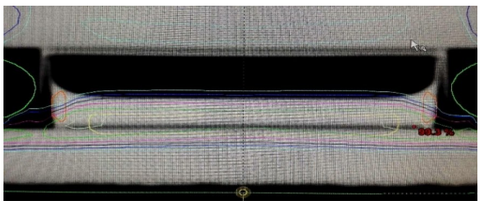
b: With side scattering

图6 10 mL(5 mm 深度)培养液机架180°照射剂量分布

Fig.6 Dose distribution at a gantry angle of 180° and culture medium of 10 mL (5 mm depths)



a: With side scattering



b: Without side scattering

图7 加与不加旁向散射时的剂量分布比较

Fig.7 Dose distribution in the irradiation with/without side scattering

差异,以期获得最佳的细胞照射方式。

通过研究发现,不同培养液深度对细胞在照射中所接受的剂量有影响。液面过低(2.5 mm)对于贴壁细胞不能提供足够的建成,导致剂量偏差5.5%;而液面过高(7.2 mm)会使最大剂量点位于贴壁细胞前,且影响换液等实验操作和浪费培养液。所以,在离体培养细胞照射中5.0 mm高的液面更为合适,偏差为4.2%且均匀性更好。

实验也发现,正面照射空腔效应也影响着实验细胞所受剂量。在0°角正面照射时,由于培养皿盖与液面之间存在一定厚度的空腔,照射时需要考虑到空腔效应对散射线的影响。而在180°照射时,细胞、培养皿和有机玻璃体板可以看作紧密连接无空腔,1 cm厚的有机玻璃板和培养皿底部可以使贴壁细胞位于6 MV的最大剂量深度1.5 cm处附近。180°机架照射比0°照射受照细胞剂量偏差更小且均匀性更好。郑祖安等[12]的研究也指出采用机臂180°加补偿物和散射体的照射方法可以避免培养皿照射时空腔效应对剂量的影响。

旁向散射对于贴底壁生长的细胞没有太大影响,而对于侧壁和悬浮生长细胞剂量有较大影响。侧壁和悬浮生长的实验细胞在照射过程中,外周细胞由于缺乏来自于外侧的旁向散射,导致培养皿侧壁细胞的剂量较培养皿中心的剂量低,采取180°照射时最大偏差可达10.5%。在培养皿外加等高液面的培养液可以为侧壁贴壁生长细胞提供散射,能改善外侧细胞剂量分布,剂量最大偏差为3.1%,平均剂量可达99.1%。

4 结 论

在离体培养细胞照射时,推荐选用5 mm高的培养液面且外加等高液面的培养液,机臂设置为180°进行照射,这样的摆位方式可尽可能减小剂量的不确定性,最大可能地提高实验结论的准确性与可靠性。

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