

## 子野小数机器跳数取整对鼻咽癌静态调强放射治疗计划剂量学的影响

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**【摘要】目的:**探讨Prowess5.1计划在鼻咽癌静态调强放疗(IMRT)计划设计时子野小数机器跳数(MU)的四舍五入取整对计划剂量学的影响。**方法:**选择33例病理诊断明确的鼻咽癌患者的IMRT计划纳入研究,分为两组计划:计划系统优化完成的原始计划组为 $P_{orig}$ ;对原始计划组的子野小数机器跳数四舍五入取整,做最终剂量计算后生成新计划组 $P_{new}$ 。两组计划所有子野形状未改变,比较两组计划的MU变化及剂量学差异。**结果:**两组计划所有靶区的CI和HI相近,差异均无统计学意义; $P_{new}$ 组靶区覆盖率、PGTVnd的 $D_{98}$ 、 $D_{95}$ 、 $D_2$ 、 $D_{mean}$ 及PTV2的 $D_{98}$ 、 $D_{95}$ , $P_{new}$ 组均低于 $P_{orig}$ 组( $P<0.05$ ),PGTVnd、PTVnx和PTV1的 $V_{100\%}$ 分别降低了1.807%、0.655%和1.258%;危及器官左颞叶的 $D_{mean}$ 差异具有统计学意义( $P<0.05$ );对于P1计划,单次 $P_{new}$ 比 $P_{orig}$ 跳数增加了1.600,差异具有统计学意义( $519.758\pm46.410$  vs  $518.158\pm46.693$ ,  $P<0.05$ )。**结论:**Prowess5.1计划在制定鼻咽癌静态调强IMRT计划时,子野小数MU的微小变化会引起剂量学的变化,临床实践中应引起重视。

**【关键词】**鼻咽癌;计划系统;调强放射治疗;小数跳数;剂量学

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## Dosimetric effects of rounding subfield monitor units up for step-and-shoot IMRT plan of nasopharyngeal carcinoma

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**Abstract: Objective** To investigate the dosimetric effects of rounding subfield monitor units (MU) up to their nearest integers in step-and-shoot intensity-modulated radiotherapy (IMRT) plans for nasopharyngeal carcinoma (NPC) which was designed by Prowess5.1 planning system. **Methods** The IMRT plans for 33 NPC patients with definite pathological diagnosis were enrolled into this study. These IMRT plans were divided into two groups, namely  $P_{orig}$  and  $P_{new}$ .  $P_{orig}$  was composed of all the original plans which had been optimized completely by the treatment planning system itself.  $P_{new}$  was a new group of which all the subfield monitor unit were rounded up to their nearest integers based on  $P_{orig}$ , and the shapes of segments in  $P_{new}$  were all the same as those in  $P_{orig}$ . The dosimetric characteristics and MU differences were recorded and compared between  $P_{orig}$  and  $P_{new}$ . **Results** The conformity index and homogeneity index of target areas in two groups were similar, without statistical significance. The target coverage, the  $D_{98}$ ,  $D_{95}$ ,  $D_2$ ,  $D_{mean}$  of PGTVnd, and the  $D_{98}$ ,  $D_{95}$  of PTV2 in  $P_{new}$  were lower than those in  $P_{orig}$  ( $P<0.05$ ). The  $V_{100\%}$  of PGTVnd, PTVnx and PTV1 were decreased by 1.807%, 0.655% and 1.258%, respectively. For organs-at-risk, only the  $D_{mean}$  of left temporal lobe showed statistical differences between two groups ( $P<0.05$ ). For P1 plans, the MU per fraction in  $P_{new}$  was increased by 1.600 MU as compared with  $P_{orig}$  ( $519.758\pm46.410$  vs  $518.158\pm46.693$ ,  $P<0.05$ ). **Conclusion** When Prowess5.1 planning system is used to design step-and-shoot IMRT plan for NPC, the tiny changes of subfield monitor units will cause dosimetric differences. Hence the calculation of monitor units should be paid attention to in clinical practice.

**Keywords:** nasopharyngeal carcinoma; treatment planning system; intensity-modulated radiotherapy; decimal monitor unit; dosimetry

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## 前言

鼻咽癌是我国常见肿瘤之一,易发于华南地区,放射治疗是鼻咽癌的主要治疗手段<sup>[1]</sup>。基于三维适形放疗技术发展起来的调强放射治疗(IMRT),掀起了放射肿瘤学史上的一次技术变革,它提高了肿瘤内剂量,改善了靶区适形度和均匀性,更好地保护了危及器官(Organs-at-Risk, OAR),大大降低了肿瘤局部复发率和正常组织并发症发生率<sup>[2-4]</sup>,目前已成为鼻咽癌的主要放疗技术。其中静态IMRT是通过一系列固定射野角度,利用多叶准直器(MLC)形成若干子野(Segment)分步照射达到要求的剂量强度分布,所有参数通过逆向治疗计划系统(TPS)精确优化得出,然后传输到医用直线加速器中执行。一般地,TPS优化出来的每个子野的机器跳数(MU)至少保留小数点后两位数值,若子野MU越小,则会增加剂量投照的不确定性<sup>[5-7]</sup>。鼻咽癌静态IMRT计划包含的子野数较多,子野形状复杂,如果在传输计划前子野小数MU未做归整处理,则有可能带来实际投照剂量更大的不确定性。本研究旨在Prowess5.1计划系统中分析子野小数机器跳数取整对鼻咽癌静态IMRT计划剂量学的影响,从而为计划传输前的质量控制及临床实践提供必要依据。

## 1 材料与方法

### 1.1 病例选择

回顾性随机选择2013年3月~2014年5月常德市第一人民医院肿瘤科收治的33例经病理和MRI确诊为无远处转移的鼻咽癌初治患者,所有患者均已行IMRT。其中男19例,女14例,年龄33~75岁(中位年龄55岁);TNM分期参照鼻咽癌中国福州2008版<sup>[8]</sup>:6例T2、14例T3、13例T4、5例N0、9例N1、16例N2、3例N3。

### 1.2 仪器设备

采用德国西门子大孔径CT模拟定位机SOMATOM AS40;德国西门子直线加速器Oncor impression plus;美国Prowess Panther5.1计划系统。

### 1.3 定位扫描

患者均采用仰卧位,头颈肩热塑模和全碳纤维头颈肩架固定,双手置于体侧;行CT增强扫描,扫描上界为头顶,下界为锁骨下2 cm,层厚与层间距均为3 mm,扫描完成后行图像质控检查,确认无误后传输至Prowess panther5.1计划系统,由临床放疗医师按统一标准勾画。

### 1.4 靶区和危及器官勾画及处方规定

靶区定义和勾画参照ICRU50、60号及2010年鼻咽癌调强放疗专家共识<sup>[9]</sup>。原发肿瘤区GTVnx,颈部

淋巴结肿大区GTVnd,高危临床靶区CTVnx,亚临床靶区CTV1,临床预防照射区CTV2,所有靶区外扩3 mm分别变成计划靶区PGTVnx、PGTVnd、PTVnx、PTV1和PTV2。处方剂量规定:PGTVnx 74.8 Gy/34次、PGTVnd 70.04 Gy/34次或74.8 Gy/34次、PTVnx 70.04 Gy/34次、PTV1 61.2 Gy/34次和PTV2 50.4 Gy/28次。勾画OAR:脊髓、脑干、晶体、视神经、视交叉、垂体、颞叶、下颌骨、腮腺和喉等,剂量限值参照RTOG0225/0615<sup>[10-11]</sup>。

### 1.5 计划设计

所有患者IMRT计划均采用9野(0°、40°、80°、120°、160°、200°、240°、280°、320°)均分共面等中心设计,射线能量6 MV,采用直接子野优化,每个射野最大子野数为9,最小子野面积为3 cm<sup>2</sup>,最小子野跳数为3 MU。所有计划设计分两程完成:首先,第一程计划按34次总处方优化,满足临床需求后,其中28次计划作为P1;其次,第二程计划优化时舍弃PTV2,同样按34次处方优化,待满足临床要求后,其中6次计划作为P2;最后合成P1和P2即完成整个计划设计,本研究所有对比均在合成计划中评价。子野MU处理方式如下:P<sub>orig</sub>组为TPS原始输出,每个子野MU保留小数点后两位;P<sub>new</sub>组是在P<sub>orig</sub>组基础上对每个子野MU四舍五入取整数,子野形状未改变。

### 1.6 计划评估

靶区剂量学评估包括:(1)最小近似剂量D<sub>98</sub>、最大近似剂量D<sub>2</sub>和D<sub>95</sub>,分别表示为98%、2%、95%的靶区体积受到的照射剂量;(2)平均剂量D<sub>mean</sub>;(3)V<sub>100%</sub>表示100%的靶区处方所包含的体积占靶区体积的百分比;(4)均匀性指数(Homogeneity Index, HI)<sup>[12]</sup>, $HI=(D_2-D_{98})/D_p$ ,式中D<sub>p</sub>为靶区剂量,HI理想值为0,并且随着计划不均匀而增大;适形指数(Comformity Index, CI)<sup>[13]</sup>, $CI=V_{t,ref}/V_t \times V_{t,ref}/V_{ref}$ ,式中V<sub>t,ref</sub>为接受剂量等于或大于参考剂量的靶区体积,V<sub>t</sub>为靶区体积,V<sub>ref</sub>为接受剂量等于或大于参考剂量的体积,CI取值0~1,值越大适形度越好。本研究OAR主要考察脊髓、脑干、晶体、视神经、视交叉和颞叶,剂量学评估为:脊髓、脑干评估最大剂量D<sub>max</sub>,1%的体积受照剂量D<sub>1</sub>;晶体、视神经、视交叉评估最大剂量D<sub>max</sub>;颞叶评价最大剂量D<sub>max</sub>,1%的体积受照剂量D<sub>1</sub>和平均剂量D<sub>mean</sub>。除此之外,还比较两组计划的MU差异。

### 1.7 统计学处理

应用SPSS 20.0软件进行统计学分析,数据以均数±标准差表示,两组数据间进行配对t检验,P<0.05表示差异具有统计学意义。

## 2 结果

### 2.1 靶区剂量对比

2.1.1 剂量分布与剂量体积直方图(DVH) 从图1可以看出,对于此患者计划,子野MU取整后的DVH

(虚线)与TPS原始计算的DVH(实线)的差异主要体现在靶区上,而危及器官几乎无差异。图2为横断面上等剂量分布比较,差异不明显。

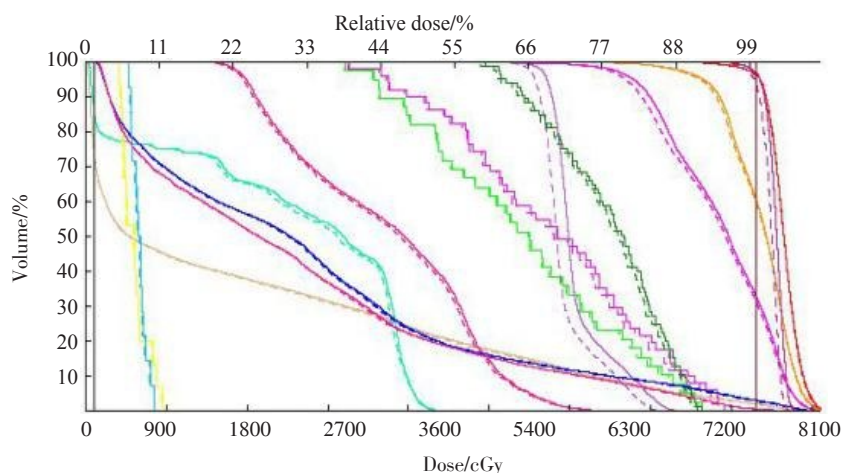


图1 某例患者DVH图

Fig.1 Dose-volume histogram of a patient

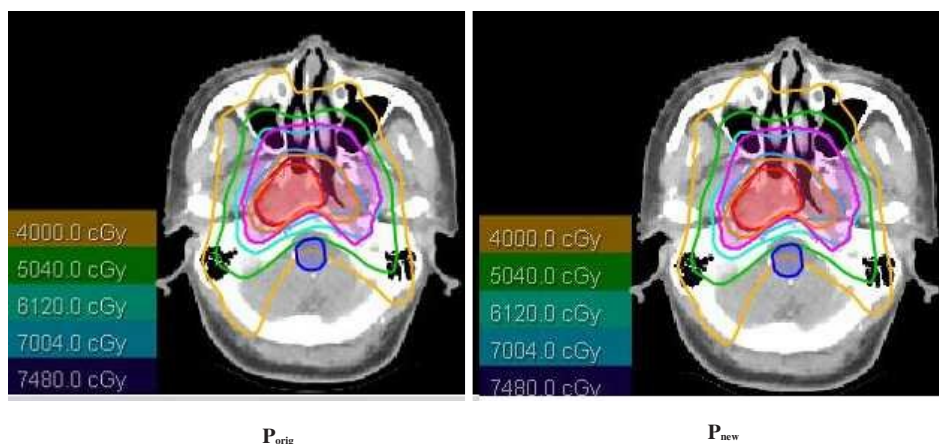


图2 横断面等剂量线分布比较

Fig.2 Isodose line distribution of transverse section

$P_{orig}$  was composed of all the original plans which had been optimized completely by the treatment planning system itself;  $P_{new}$  was a new group of which all the subfield monitor unit were rounded up to their nearest integers based on  $P_{orig}$ . The shapes of segments in  $P_{new}$  were all the same as those in  $P_{orig}$ .

2.1.2 靶区剂量比较 由表1可知,PGTVnd的 $D_{98}$ 、 $D_{95}$ 、 $D_2$ 和 $D_{mean}$ 、PTV2的 $D_{98}$ 和 $D_{95}$ ,子野取整组 $P_{new}$ 均低于TPS原始计算组 $P_{orig}$ ,差异具有统计学意义( $P < 0.05$ );对于靶区覆盖率,所有靶区 $P_{new}$ 组均低于 $P_{orig}$ 组,PGTVnd、PTVnx和PTV1的 $V_{100\%}$ 差异具有统计学意义( $P < 0.05$ ),分别降低了1.807%、0.655%和1.258%;两组计划所有靶区的CI和HI相近,均无统计学意义。

### 2.2 主要危及器官剂量比较

由表2可以看出,两种MU处理方式下,对于所考察的OAR,所有 $P_{new}$ 的 $D_{max}$ 较 $P_{orig}$ 稍小,右视神经、视交叉及左右颞叶的 $D_i$ 亦稍小;脊髓、脑干、左视神经的 $D_i$ 及右颞叶的 $D_{mean}$ , $P_{new}$ 较 $P_{orig}$ 稍大,但以上均无统计学意义,仅左颞叶的 $D_{mean}$ 差异具有统计学意义( $P < 0.05$ )。

### 2.3 机器跳数的变化

由图表3可知,两种MU不同处理方式下,对于P1计划,单次 $P_{new}$ 比 $P_{orig}$ 跳数增加了1.600,差异具有统计学意义( $P < 0.05$ )。

表1 P<sub>new</sub>与P<sub>orig</sub>的靶区剂量学参数比较(  $\bar{x} \pm s$  )

Tab.1 Dosimetric comparison of target areas between P<sub>new</sub> and P<sub>orig</sub> (Mean±SD)

Target area	Parameter	P <sub>orig</sub>	P <sub>new</sub>	P value
PGTVnx	D <sub>98</sub> /cGy	7 355.727±110.182	7 347.576±99.866	0.427
	D <sub>95</sub> /cGy	7 484.849±75.105	7 478.182±75.359	0.482
	D <sub>2</sub> /cGy	7 948.939±146.518	7 950.091±155.853	0.901
	D <sub>mean</sub> /cGy	7 713.306±95.109	7 710.049±104.999	0.732
	V <sub>100</sub> /%	95.950±1.694	94.342±5.855	0.151
	HI	0.080±0.027	0.080±0.026	0.488
	CI	0.655±0.064	0.645±0.065	0.072
PGTVnd	D <sub>98</sub> /cGy	7 283.667±216.493	7 252.222±190.299	0.015*
	D <sub>95</sub> /cGy	7 375.963±211.298	7 341.111±186.919	0.009*
	D <sub>2</sub> /cGy	7 794.074±227.261	7 773.000±216.989	0.140
	D <sub>mean</sub> /cGy	7 580.978±212.234	7 553.515±196.403	0.034*
	V <sub>100</sub> /%	95.659±2.129	93.852±3.633	0.021*
	HI	0.069±0.024	0.069±0.023	0.490
	CI	0.655±0.057	0.652±0.056	0.301
PTVnx	D <sub>98</sub> /cGy	6 796.852±193.652	6 776.333±206.397	0.035*
	D <sub>95</sub> /cGy	7 006.148±101.756	6 991.778±121.688	0.151
	D <sub>2</sub> /cGy	7 906.370±103.679	7 899.667±125.142	0.520
	D <sub>mean</sub> /cGy	7 496.478±84.957	7 483.256±103.798	0.198
	V <sub>100</sub> /%	95.237±1.854	94.582±2.559	0.047*
	HI	0.159±0.036	0.161±0.035	0.161
	CI	0.628±0.064	0.623±0.054	0.413
PTV1	D <sub>98</sub> /cGy	5 881.182±115.793	5 860.515±117.839	0.083
	D <sub>95</sub> /cGy	6 124.727±66.104	6 102.667±94.852	0.073
	D <sub>2</sub> /cGy	7 832.212±116.712	7 832.212±131.565	0.555
	D <sub>mean</sub> /cGy	6 819.558±114.876	6 804.224±131.306	0.155
	V <sub>100</sub> /%	94.867±0.992	93.609±3.391	0.040*
	HI	0.319±0.031	0.322±0.031	0.071
	CI	0.762±0.037	0.759±0.041	0.383
PTV2	D <sub>98</sub> /cGy	4 963.710±118.264	4 930.936±79.333	0.026*
	D <sub>95</sub> /cGy	5 095.871±79.396	5 061.774±54.545	0.016*
	D <sub>2</sub> /cGy	6 327.774±114.606	6 295.645±106.086	0.066
	D <sub>mean</sub> /cGy	5 462.658±128.790	5 432.294±106.660	0.113
	V <sub>100</sub> /%	96.374±2.007	95.761±1.518	0.055
	HI	0.270±0.024	0.271±0.023	0.721
	CI	0.664±0.044	0.665±0.048	0.900

HI: Homogeneity index; CI: Conformity index; \*P<0.05



表2  $P_{\text{new}}$ 与 $P_{\text{orig}}$ 的危及器官剂量学参数比较( $\bar{x} \pm s$ )Tab.2 Dosimetric comparison of organs-at-risk between  $P_{\text{new}}$  and  $P_{\text{orig}}$  ( $\text{Mean} \pm \text{SD}$ )

Organs-at-risk	Parameters/cGy	$P_{\text{orig}}$	$P_{\text{new}}$	$P$ value
Spinal cord	$D_{\text{max}}$	3 867.364±115.730	3 865.579±110.232	0.781
	$D_1$	3 736.939±118.571	3 737.546±123.960	0.926
Brain stem	$D_{\text{max}}$	5 580.203±350.935	5 577.116±354.777	0.709
	$D_1$	5 264.424±331.259	5 267.091±341.448	0.764
Lens-L	$D_{\text{max}}$	672.739±234.834	672.346±234.639	0.819
Lens-R	$D_{\text{max}}$	700.388±209.744	698.052±211.100	0.154
Optic nerve-L	$D_{\text{max}}$	5 097.866±1469.132	5 095.349±1452.923	0.816
	$D_1$	5 092.909±1465.217	5 094.909±1452.894	0.769
Optic nerve-R	$D_{\text{max}}$	5 200.779±1524.368	5 179.467±1545.738	0.406
	$D_1$	5 201.273±1524.211	5 170.909±1536.057	0.198
Optic chiasm	$D_{\text{max}}$	5 329.194±1775.097	5 315.489±1767.412	0.101
	$D_1$	5 325.667±1771.210	5 314.849±1766.464	0.180
Temporal lobe-L	$D_{\text{max}}$	6 917.827±807.240	6 903.191±797.388	0.213
	$D_1$	6 540.879±935.577	6 516.394±928.764	0.106
	$D_{\text{mean}}$	2 289.888±992.994	2 278.391±991.047	0.026*
Temporal lobe-R	$D_{\text{max}}$	7 183.073±662.768	7 171.858±657.427	0.318
	$D_1$	6 782.546±636.357	6 773.424±629.303	0.390
	$D_{\text{mean}}$	2 358.773±971.577	2 373.024±945.270	0.493

\* $P < 0.05$ 表3  $P_{\text{new}}$ 与 $P_{\text{orig}}$ 的MU数比较( $\bar{x} \pm s$ )Tab.3 Comparison of monitor units between  $P_{\text{new}}$  and  $P_{\text{orig}}$  ( $\text{Mean} \pm \text{SD}$ )

Plan	$P_{\text{orig}}$	$P_{\text{new}}$	$P$ value
P1	518.158±46.693	519.758±46.410	0.007
P2	523.257±47.097	524.065±47.570	0.251

### 3 讨论

相对传统放疗技术,鼻咽癌IMRT具有明显的剂量学优势,不仅改善患者生存质量,而且大大提高了肿瘤局控率<sup>[14]</sup>。静态IMRT则是利用MLC形成多个子野分步照射,每个子野照射完毕后,照射切断,MLC形成下一个子野,继续照射,待所有子野照射完成,束流强度叠加形成所需剂量分布。为达到一个满意的临床需求,鼻咽癌静态IMRT计划往往包含多个子野,并且子野形状复杂、子野MU较小,由于加速器的启动特性、射线开关动作以及靶区本身运动等,小子野及小MU投照具有很大不确定性<sup>[15-16]</sup>。如徐英杰等<sup>[17]</sup>在研究西门子加速器启动特性时报道:MU<2时射线束不稳定,所有指标

重复性差,部分或所有指标不符合临床要求;MU≥2时每个MU的剂量差别<0.1%,射野平坦度和对称性能满足临床要求。目前有关小数位MU的研究非常少,多数集中在对小MU的研究。Nithya等<sup>[16]</sup>报道:对于剂量线性,当执行1 MU时误差达到4.2%,当大于1 MU时误差<2%。另外,对小MU的剂量特性研究,不同厂家的加速器,得出的结果不尽相同:Bhangle等<sup>[15]</sup>在Siemens Oncor impression加速器上研究6 MV和15 MV线性,≥2 MU时只有2%,1 MU时大概12%;Kang等<sup>[18]</sup>发现Varian 21EX加速器在小MU时剂量误差超过10%,射野平坦度和对称性在MU减少至1时有变差。Fujimoto等<sup>[19]</sup>报道医科达机器1 MU时标准差在±5%,每个子野2 MU时则降至±1.2%。

本研究试图在小子野和小MU的基础上分析鼻咽癌静态IMRT计划中,小数MU取整对计划质量的影响,由图1、表1不难看出,小数MU取整后,部分靶区剂量学参数影响较大,尤其是对PGTVnd较敏感,其 $D_{98}$ 、 $D_{95}$ 、 $D_{\text{mean}}$ 及 $V_{100\%}$ 差异均有统计学意义,这可能与PGTVnd靶区体积较小有关;其次,PGTVnd剂量-体积曲线图较陡,且CI相对较好,MU微小变化可能会引起靶区覆盖

率等参数较大的变化;另外,有研究报道MLC的叶片宽度与靶区覆盖率等剂量学参数相关<sup>[20-21]</sup>。本研究MLC在等中心的宽度为1 cm,对于淋巴结这样精细靶区的剂量学控制欠佳,小数MU的变化可能会影响计划质量。临床研究表明鼻咽癌的局部控制率与靶体积的照射剂量呈正相关<sup>[22]</sup>,放疗后GTV等靶区体积缩小明显<sup>[23]</sup>,并且原发肿瘤及颈部淋巴结体积大小与鼻咽癌的预后相关<sup>[24]</sup>。因而在保护OAR的同时应最大限度提高目标剂量的靶区覆盖率。本研究中PGTVnx、PGTVnd、PTVnx、PTV1以及PTV2靶区覆盖率 $V_{100\%}$ 在小数MU取整后分别降低了1.608%、1.807%、0.655%和1.258%,故小数MU在TPS中的处理问题不容忽视。对于Prowess Panther5.1系统,若子野MU取整前后DVH评价差异超出临床允许范围,应该重新优化计划,待小数MU处理后再评估,直至实际投照的计划满足临床需求。

综上所述,对于Prowess Panther5.1,每个子野小数MU的取整(实际执行需要)对计划质量会有一定影响,应引起物理师和放疗医师足够重视,计划传输前做好必要质控(计划再评估、小野、小数MU核查及处理等)以确保放疗实施的精确性。未来,期待伴随放疗新设备、放疗技术和计算机技术的发展,TPS中子野MU的计算精度在加速器中能如实执行。

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