UDC: 616-006.6+615.849
DOI: 10.52532/2663-4864-2021-1-59-25-30

A.S. RAKHIMOV[1], M.D. ZEKEBAYEV[2], A. KUATBEK[3], V.V. DYACHKOV[1]

[1]al-Farabi Kazakh National University, Almaty, the Republic of Kazakhstan;
[2]Asfendiyarov Kazakh National Medical University, Almaty, the Republic of Kazakhstan;
[3]Kazakh Institute of Oncology and Radiology, Almaty, the Republic of Kazakhstan

Comparison of dosimetry parameters of three-dimensional conformational radiation therapy and volumetric modulated arc therapy on the example of treatment of a patient with salivary gland adenocarcinoma

Relevance: *An optimal choice of radiation therapy method is the main prerequisite for successful completion of treatment. Continuous analysis of radiation therapy methods' advantages and comparing their parameters and dose load in typical cases will increase the treatment efficacy and reduce the unavoidable load on critical organs.*

The purpose *was to check the plans of treatment by volumetric modulated arc therapy (VMAT) and three-dimensional conformal radiation therapy (3D-CRT) methods, make their comparison and identify the advantages using an example of a treatment design for a patient treated at the Daily Radiotherapy Hospital of the Kazakh Institute of Oncology and Radiology (Almaty, Kazakhstan).*

Results: *The presented illustrations of the process planning and the numerical analysis of the dose load on critical organs show VMAT advantages for radiation therapy of salivary gland cancer: optimal coverage, sparing load on critical organs and healthy tissues, gradient decay at the borders of the neoplasm.*

Conclusion: *The variability of radiation therapy methods ensures the most acceptable coverage that keeps the dose load within international standards' ranges. Mastering these methods will improve the effectiveness of radiation therapy for various cancer cases.*

Keywords: *Volumetric modulated arc therapy (VMAT), three-dimensional conformal radiation therapy (3D-CRT), radiation therapy (RT).*

Introduction: Modern radiation therapy (RT) is a scientific discipline based on fundamental physical, technical, radiobiological, biophysical, and medical reasoning. RT can only be effective if the following conditions are met: the prescribed dose is correctly applied to the tumor site; the radiation exposure to surrounding critical organs and healthy tissues is minimized; the spatial distribution of dose is optimized, taking into account the heterogeneity of the body environment, and the impact of dose distribution on the probability of radiation complications in normal organs and tissues is considered and quantified (Table 1) [1].

Table 1 – Tolerable doses for some tissues and organs (QUANTEC).

Body organ	DT 5/5* (Gr)			Radiobiological parameters (for V3/3)		DT 50/5** (Gr)			Radiobiological parameters (for V3/3)	
	V 3/3	V 2/3	V 1/3	BED***	ESD****	V 3/3	V 2/3	V 1/3	BED***	ESD****
Spinal cord	47	50	50	91,7	46,0	---	70	70	139,0	70,0
Esophagus	55	58	60	99,7	56,0	68	70	72	117,0	66,0
Larynx	44	45	---	78,6	44,0	80	---	---	---	---
Trachea	70	70	70	125,0	70,3	80	80	80	143,0	80,3

DT 5/5 (minimum tolerance dose)** – the minimum tolerable dose, in which the probability of developing late radiation injuries within five years after the end of the radiation therapy course is **5%.
****DT50/5 (maximum tolerance dose)** – the maximum tolerable dose, in which the probability of developing late radiation injuries within five years after the end of the radiation therapy course is **50%.***
*****Biologically effective dose (BED) -** the dose required to be administered to reach the same effect as if the dose would be administered endlessly a large number of infinitely small single doses.*
****** Equivalent summary dose (ESD) -** dose of the standard course equivalent in effect, considering the tumor proliferation.*

The current RT development stage is characterized by an intensive search for quantitative relationships between modes of radiation exposure on the irradiated body and the radiation effects and the use of these relationships to optimize the physical conditions of irradiation of malignant tumors [2].

Materials and Methods: The contours of the detected tumor (Gross Tumor Volume, GTV) and critical or-

gans are entered in each slice of a series of the patient's tomographic images. CTV is the volume to which the planned dose is applied, considering the estimated clinical spread of the tumor. PTV is the planned target volume [3]. The main criterion for an optimal plan is uniform irradiation of the tumor at the prescribed dose and create a high dose gradient just outside the PTV boundaries [4] (Figure 1).

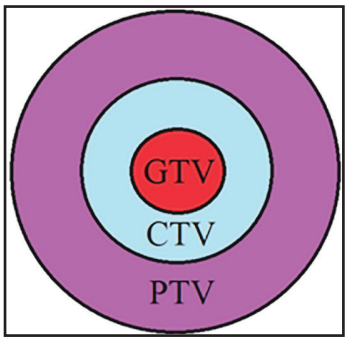

Figure 1 – Illustration of irradiation boundaries.

In three-dimensional conformal radiation therapy (3D-CRT), the axes of all the beams are directed to the same isolation center point. The complex shape of the beam corresponding to the target contour on modern linear accelerators is achieved using multistage collimators [5]. The IMRT technique is that the movement of the blades of a multiple-blade collimator creates a complex pattern of dose distributions to follow the shape of the target. Many fields are applied to create a larger dose gradient outside the boundaries of the target. The greater the number of fields, the greater the dose gradient can be achieved [6]. A conventionally infinite number of fields is realized by rotating the gantry (the moving part of the RT apparatus) of the accelerator during irradiation [7].

High conformity of dose distributions can be obtained by applying multiple static fields or dynamic arcs [8]. One such technique is volumetric modulated arc therapy (VMAT) [9]. VMAT is a treatment technique that uses one or more gantry rotation arcs with continuously varying MLC collimator aperture, gantry speed, and dose delivery intensity [10-12]. One of the advantages of VMAT over tomotherapy is the possibility to provide treatment using conventional linear accelerators with a suitable configuration [13, 14].

The main VMAT advantage over 3D-CRT is the increased therapeutic efficacy due to reduced exposure time and the number of monitor units, with a consequent reduction in the integrated irradiation dose on the whole body [15, 16]. Monitor units measure the output power of a clinical accelerator for radiotherapy [17].

The additional time saved by the ergonomics of the method allows using modern visual control tools (image-guided radiation therapy, IGRT). This system utilizes images obtained before and/or during treatment for more accurate treatment delivery verification. Adaptive strategies can improve treatment accuracy [18, 19]. The main disadvantages of other methods are that they need more time on the couch and increase the total patient's irradiation dose. These disadvantages are less significant in arc therapy due to shorter delivery times and fewer monitor units [20].

Patient information:

Patient A.

Diagnosis: Salivary gland adenocarcinoma, with necrotic foci, invasive growth, and metastasis to 5 of 7 lymph nodes. Post-operative radiotherapy is recommended for primary focus and regional metastases.

Clinical data: Total dose: 54 Gray. After delineating the layer-by-layer sections of CT images, the volume of subsequent exposure and the organs at risk were distinguished [21] (Figure 2). The above-mentioned CTV volumes (marked dark green and red on the CT image for the tumor and the affected lymph nodes) required special attention. A prescribed dose of radiation was administered to those sites. The organs at risk in those sections included the spinal cord (purple), larynx (blue), trachea (yellow), and esophagus (blue). The bones were shown in light green. As seen in Figure 2, the organs at risk were inevitably exposed to radiation [22, 23]. Therefore, in that case, the task was to make the dose loads tolerable for the critical organs and tissues according to the regulations (Table 1).

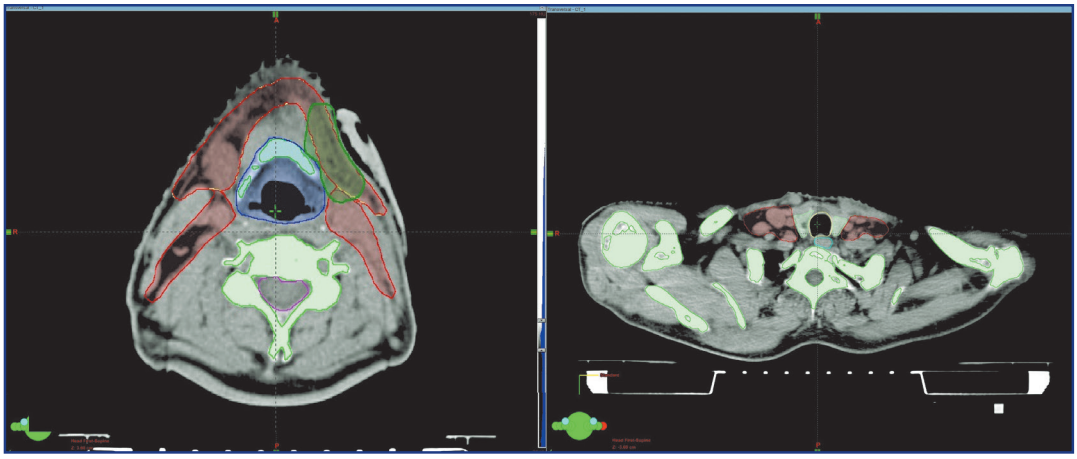

Figure 2 – Patient A., 58 years, salivary gland adenocarcinoma. Contouring of risk organs and radiation volumes on selected CT scans

The radiation plan prepared for 3D conformal radiotherapy and VMAT in Eclipse is stored in the oncology department's database. Judging by the plans, CTV and PTV areas receive the maximum dose load (Figure 3); on the edges, the irradiation volume diminishes abruptly (gradient) to minimize damage to critical organs. Both plans can be displayed to compare the coverage in both methods (Figure 4).

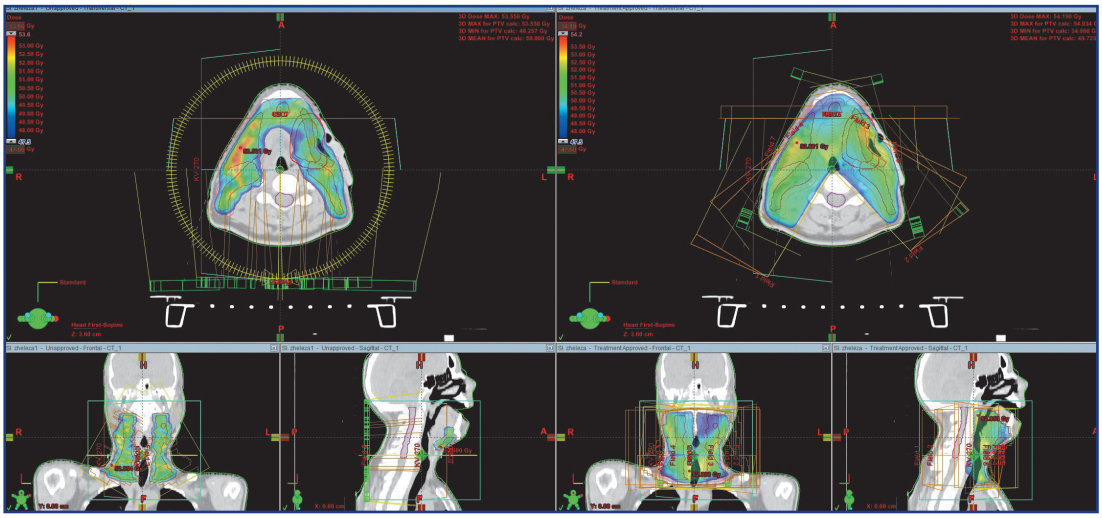

Figure 3 – Patient A., 58 years, salivary gland adenocarcinoma. Comparison of VMAT and 3D-CRT coverage areas (1st layer)

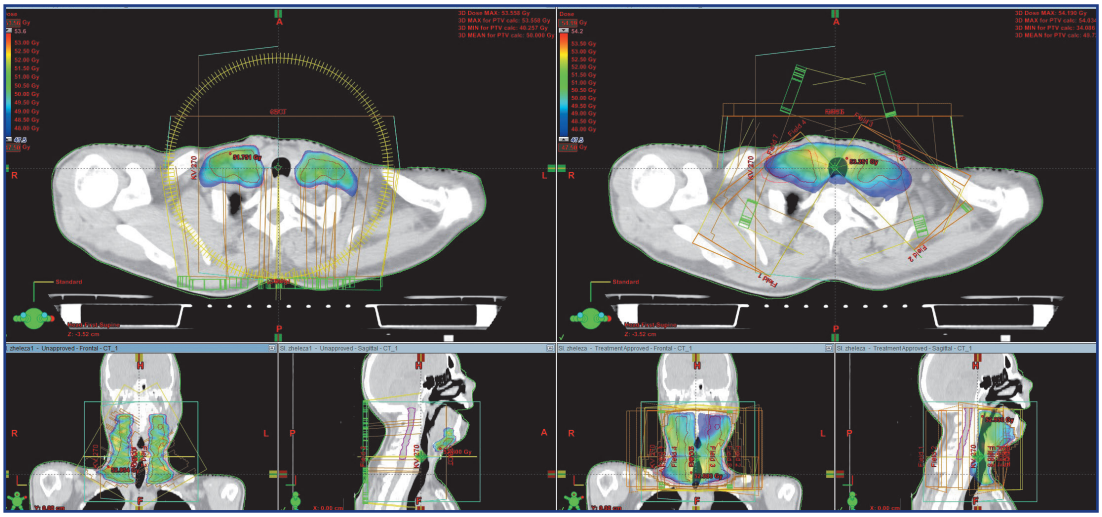

Figure 4 – Patient A., 58 years, salivary gland adenocarcinoma. Comparison of VMAT and 3D-CRT coverage areas (2nd layer)

Discussion and Results:

The images show that VMAT delivered a gentler coverage; healthy tissues and organs were less stressed than in 3D conformal therapy; some critical organs like the trachea were not significantly affected by irradiation.

Figures 5 and 6 show the specifics of each method: the monitor units, rotation degrees (for VMAT), parameters and number of fields (for 3D), the equipment needed. Dose distribution figures are shown in Figures 7 and 8.

Field ID	Machine/Energy	MLC	Gantry Rtn [deg]	MU	Field X [cm]	Field Y [cm]
KV 270	Clinac 2100CD - 6X		270.0		22.7	19.9
KV 0	Clinac 2100CD - 6X		0.0		22.7	19.9
CBCT	Clinac 2100CD - 6X		0.0		22.7	19.9
Field 1	Clinac 2100CD - 6X	Static	211.0	73	17.2	9.2
Field 7	Clinac 2100CD - 6X	Static	290.0	14	17.5	16.4
Field 4	Clinac 2100CD - 6X	Static	316.0	40	17.1	11.2
Field 6	Clinac 2100CD - 6X	Static	0.0	105	23.2	6.8
Field 5	Clinac 2100CD - 6X	Static	0.0	98	18.7	9.7
Field 3	Clinac 2100CD - 6X	Static	31.0	39	17.1	12.2
Field 8	Clinac 2100CD - 6X	Static	75.0	14	17.4	16.4
Field 2	Clinac 2100CD - 6X	Static	136.0	70	17.3	7.7

Figure 5 – Field parameters for 3D-CRT

Field ID	Machine/Energy	MLC	Gantry Rtn [deg]	Coll Rtn [deg]	Field X [cm]	Field Y [cm]	MU
KV 270	TrueBeamSN2059 - 6X		270.0	0.0	22.7	19.9	
KV 0	TrueBeamSN2059 - 6X		0.0	0.0	22.7	19.9	
CBCT	TrueBeamSN2059 - 6X		0.0	0.0	22.7	19.9	
Field 1	TrueBeamSN2059 - 6X	VMAT	181.0 CW 179.0	30.0	22.7	19.9	191
Field 2	TrueBeamSN2059 - 6X	VMAT	179.0 CCW 181.0	330.0	22.7	19.9	216

Figure 6 – Field parameters for VMAT

Structure	Volume [cm³]	Min Dose [Gy]	Max Dose [Gy]	Mean Dose [Gy]
BODY	15433.5	0.000	54.190	9.319
Bones of Skull	1720.3	0.000	54.112	9.519
Trachea	26.7	2.003	54.193	29.904
CTV	34.2	43.608	53.203	50.779
PTV total lymp	700.5	0.000	54.041	48.864
PTV calc	678.5	34.086	54.034	49.725
CTV total	304.0	39.490	53.203	50.015
Nodi Lymph IV	40.2	46.014	53.125	50.148
Nodi Lymph V	48.7	39.578	51.830	48.073
nodi lymph III	50.9	46.564	52.481	50.691
nodi lymph II	80.2	47.385	52.033	49.866
nodi lymph I	75.9	42.438	53.203	50.807
paritid l	22.7	2.303	51.302	29.965
paritid r	21.4	3.662	52.873	34.861
Thyroid	8.1	49.792	53.372	51.890
Cochlea L	3.3	1.305	2.235	1.682
Mandibulae	80.6	1.484	54.112	41.168
Brain	1476.5	0.000	27.103	0.897
Cochlea R	3.4	1.320	2.259	1.703
Larynx	52.2	42.717	54.061	51.042
Esophagus	6.0	1.746	50.073	26.547
Spinal Cord	16.5	14.656	41.239	37.628
PTV	79.5	0.018	53.520	50.334
ring	14318.0	0.000	54.190	6.298
PTV calc loca	76.3	40.625	53.520	50.674

Figure 7 – Dose load on critical organs in 3D conformal therapy

Structure	Volume [cm³]	Min Dose [Gy]	Max Dose [Gy]	Mean Dose [Gy]
BODY	15433.5	0.000	53.558	8.827
Bones of Skull	1720.3	0.004	52.584	8.819
Trachea	26.7	2.504	50.532	24.469
CTV	34.2	44.636	53.265	50.064
PTV total lymp	700.5	0.000	53.558	49.252
PTV calc	678.5	40.257	53.558	50.000
CTV total	304.0	43.872	53.558	50.568
Nodi Lymph IV	40.2	48.397	53.509	50.557
Nodi Lymph V	48.7	44.189	53.509	50.562
nodi lymph III	50.9	47.549	53.371	50.593
nodi lymph II	80.2	48.013	52.847	50.583
nodi lymph I	75.9	43.858	53.558	50.533
paritid l	22.7	2.903	50.924	27.922
paritid r	21.4	3.280	51.280	27.909
Thyroid	8.1	39.682	52.115	47.970
Cochlea L	3.3	1.411	2.324	1.799
Mandibulae	80.6	1.716	52.584	35.457
Brain	1476.5	0.132	13.639	0.766
Cochlea R	3.4	1.340	2.312	1.793
Larynx	52.2	26.580	51.760	43.359
Esophagus	6.0	2.038	45.112	22.184
Spinal Cord	16.5	7.121	41.658	34.682
PTV	79.5	0.009	53.443	49.531
ring	14318.0	0.000	48.232	5.837
PTV calc loca	76.3	40.973	53.443	49.877

Figure 8 – Dose load in VMAT

These tables demonstrate the critical organs' volumes, dose range, and average dose. Both methods meet the radiation exposure requirements compared to international QUANTEC regulations. However, the numerical analysis testifies that VMAT provides a more optimal treatment. Critical organs and healthy tissue are less stressed, and clinical volumes are dosed within the prescribed limits (with a permissible variation of 5%). The graph shows that the peak dosage is achieved in the volumes required for therapy, while the critical organs' exposure remains within the normal range (Figure 9) [20, 24].

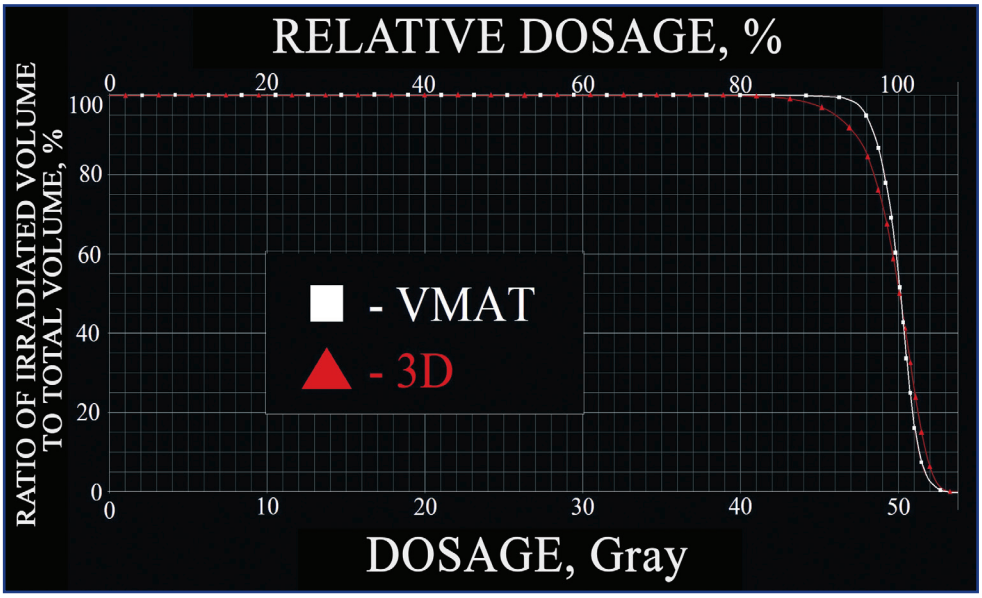

Figure 9 – PTV dose distribution graph for two plans

Conclusions:

This paper describes a calculated patient plan for a day hospital radiotherapy unit at the Kazakh Institute of Oncology and Radiology (Almaty, Kazakhstan). The treatment plans tested included VMAT and 3D conformal radiation therapy. The authors reviewed the methods and discussed their advantages and disadvantages in an actual clinical case study. They analyzed the current practice of using VMAT and the available research data on planning and clinical outcomes at different tumor sites. This modern method has obvious advantages over other methods. However, its use has some limitations that require new practical medical, physical, and technological studies. Nevertheless, both methods are widely and successfully applied for therapy in medical institutions. Proficiency in these and other radiotherapy techniques will improve the effectiveness of treatment for a wide range of cancers.

This analysis of the clinical case proves VMAT as the best method for salivary gland cancer therapy and confirms the feasibility of its use in medical institutions.

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ТҰЖЫРЫМ

А.С. Рахимов[1], М.Д. Зекебаев[2], А. Қуатбек[3], В.В. Дьячков[1]

[1]әл-Фараби атындағы ҚазҰУ, Алматы, Қазақстан Республикасы;
[2]С.Ж. Асфендияров атындағы Қазақ ұлттық медицина университеті, Алматы, Қазақстан Республикасы;
[3]«Қазақ онкология және радиология ғылыми-зерттеу институты» АҚ, Алматы, Қазақстан Республикасы

Сілекей безінің аденокарциномасына шалдыққан науқасты емдеу жоспары мысалында үш өлшемді конформды сәулелік терапия мен айналмалы көлемді-модуляцияланған сәулеленудің дозиметриялық параметрлерін салыстыру

Өзектілігі: *емдеу курсын сәтті аяқтаудың негізгі мәселесі - сәулелік терапия әдісін оңтайлы таңдау болып табылады. Сәулелік терапияның қолданыстағы әдістерінің артықшылықтары үздіксіз талдау, әдеттегі жағдайлар мен олардың жиынтықтары үшін олардың параметрлері мен дозалық жүктемесін салыстыру емдеу тиімділігін арттырады және сыни органдарға еріксіз жүктемелерді азайтады.*

Зерттеу мақсаты: *Қазақ онкология және радиология ғылыми-зерттеу институтының сәулелік терапияның күндізгі стационарындағы науқастың есептеу жоспарының мысалында айналмалы көлемді-модуляцияланған сәулелену (VMAT) және үш өлшемді конформды сәулелік терапия (3D-CRT) әдісімен орындалған емдеу жоспарларын тексеруді жүзеге асыру, оларды кейіннен салыстыру және қандай да бір әдістің артықшылықтарын анықтау.*

Нәтижелері: *жоспарлау процесінің ұсынылған суреттерінде және сыни органдарға дозалық жүктемені сандық талдауда quantec тіндері мен мүшелеріне арналған толерантты дозалар нормалары шеңберінде жоспарға тексеру жүргізілді. Сілекей бездерінің қатерлі ісігін радиациялық емдеуде VMAT-тың қанағаттанарлық артықшылықтары: оңтайлы кесу, сыни органдар мен сау тіндерге жұмсақ жүктеме, неоплазманың шекарасындағы градиентті төмендеуі.*

Қорытынды: *сәулелік терапия әдістерінің өзгермелілігі халықаралық нормативтер диапазонында дозалық жүктемені ұстап тұруға мүмкіндік беретін неғұрлым қолайлы жабынды жүзеге асыруға мүмкіндік береді. Осы әдістердің арасында кәсіби бағдарлау әртүрлі онкологиялық аурулар үшін сәулелік терапияның тиімділігін арттыруға мүмкіндік береді.*

Түйінді сөздер: *айналмалы көлемді-модуляцияланған сәулелену (VMAT), үш өлшемді конформды сәулелік терапия (3D-CRT), сәулелік терапия.*

АННОТАЦИЯ

А.С. Рахимов[1], М.Д. Зекебаев[2], А. Куатбек[3], В.В. Дьячков[1]

[1]Казахский Национальный Университет им. аль-Фараби, Алматы, Республика Казахстан;
[2]Казахский Национальный Медицинский Университет им. С.Д. Асфендиярова, Алматы, Республика Казахстан;
[3]АО «Казахский научно-исследовательский институт онкологии и радиологии», Алматы, Республика Казахстан

Сравнение дозиметрических параметров трехмерной конформной лучевой терапии и ротационного объемно-модулированного облучения на примере плана лечения пациента с аденокарциномой слюнной железы

Актуальность: *Оптимальный выбор метода лучевой терапии является основным вопросом успешного прохождения лечебного курса. Непрерывный анализ преимуществ существующих методов лучевой терапии, сравнение их параметров и дозовой нагрузки для типичных случаев и их совокупностей позволит повысить эффективность лечения и снизить неизбежные нагрузки на критические органы.*

Цель исследования: *на примере расчетного плана пациента дневного стационара лучевой терапии Казахского научно-исследовательского института онкологии и радиологии (Алматы, Казахстан) осуществить проверку лечебных планов, выполненных методом ротационного объемно-модулированного облучения (VMAT) и трехмерной конформной лучевой терапии (3D-CRT), провести их последующее сравнение и выявления преимуществ того или иного метода.*

Результаты: *Представленные иллюстрации процесса планирования и численный анализ дозовой нагрузки на критические органы показывают преимущества VMAT для лучевой терапии рака слюнных желез: оптимальное покрытие, щадящая нагрузка на критические органы и здоровые ткани, градиентный спад на границах новообразования.*

Заключение: *Вариативность методов лучевой терапии позволяет осуществлять наиболее приемлемое покрытие, позволяющее удерживать дозовую нагрузку в диапазонах международных нормативов. Профессиональное владение этими методами позволит повысить эффективность лучевой терапии для различных онкологических заболеваний.*

Ключевые слова: *ротационное объемно-модулированное облучение (VMAT), трехмерная конформная лучевая терапия (3D-CRT), лучевая терапия (ЛТ).*

Corresponding author:
Adil Rakhimov, *e-mail: adil.s.rakhimov@gmail.com*