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EVALUATION OF THE EFFECTS OF BIOLOGICAL AND PHYSICAL OPTIMIZATION FUNCTIONS ON THE QUALITY OF RADIATION THERAPY PLANS WITH SIMULTANEOUS DOSE ESCALATION FOR PROSTATE TUMORS

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ОЦЕНКА ВЛИЯНИЯ БИОЛОГИЧЕСКИХ И ФИЗИЧЕСКИХ ФУНКЦИЙ ОПТИМИЗАЦИИ НА КАЧЕСТВО ПЛАНОВ ЛУЧЕВОЙ ТЕРАПИИ С ОДНОВРЕМЕННОЙ ЭСКАЛАЦИЕЙ ДОЗЫ ОПУХОЛЕЙ ПРЕДСТАТЕЛЬНОЙ ЖЕЛЕЗЫ

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Аннотация. *Целью данной работы является исследование и оценка влияния биологических и физических функций оптимизации на качество планов лучевой терапии с одновременной эскалацией дозы опухолей предстательной железы. В рамках данного исследования были рассмотрены дозиметрические планы 9 пациентов с диагнозом рак предстательной железы. Терапевтические планы созданы на основе дозиметрических критериев для каждого клинического случая с разными функциями оптимизации: физические, биологические, комбинация физических и биологических функций.*

Introduction. One of the most high-tech modern ways to treat cancer patients is radiation therapy (RT). The main task of radiation therapy is the exact delivery of the radiation dose to the tumor with the minimal possible radiation exposure to the surrounding healthy organs and tissues. Over the past few decades, radiation therapy has seen technical progress in treatment aspects and dose delivery technologies, allowing a transition from 3-dimensional conformal radiotherapy (3D-CRT) to intensity modulated radiation therapy (IMRT) [1]. Inverse (reverse) planning is used when developing a dosimetric plan for intensity modulated radiotherapy. The radiation therapy planning system (TPS) optimizes the dosimetric plans by means of optimization functions, simulating different tissue types and regulating the value of the radiation response. The optimization functions, in turn, are divided into biological and physical [2]. To achieve maximal therapeutic effect with minimal radiation exposure to normal organs and tissues in inverse radiation therapy planning it is necessary to determine not only optimal physical and technical parameters of irradiation (the number of beams, the gantry angle, the collimator angle, etc.), but also optimal combinations of optimization weight functions [3].

The purpose of this work is to research and evaluate the effects of biological and physical optimization functions on the quality of radiation therapy plans with simultaneous dose escalation for prostate tumors.

Research methods. Based on the anatomical data of nine patients diagnosed with prostate cancer who were treated at Tomsk Regional Oncologic Dispensary, plans of radiation therapy with volumetric modulated arc therapy (VMAT) were developed. All the patients underwent topometric preparation in the treatment position on a Toshiba Aquilion spiral CT scanner (Toshiba, Japan) with a slice thickness of 3 mm, using appropriate external immobilizing devices.

A procedure for delineation of the organs at risk (OAR) and planned target volumes (PTV) was performed, where PTV1 represents the prostate region, PTV2 is the prostate and seminal vesicles, and PTV3 is the prostate, seminal vesicles, and regional lymph nodes. The following critical structures were identified: bladder, rectum, and femoral heads. The prescribed dose per course of radiation therapy with simultaneous dose escalation SIB (Simultaneous integrated boost) was 75 Gy, which was delivered in 25 fractions, thus the single focal dose varied for PTV1- 3 Gy, for PTV2 -2.5 Gy, and for PTV3 -2 Gy.

Dosimetric planning for simultaneous integrated SIB dose escalation was performed in the Monaco environment (version 5.51.10) using volumetric intensity modulation VMAT for photon beams of the Elekta Synergy high-energy linear accelerator at the Tomsk Regional Oncologic Dispensary. All the dosimetric irradiation plans had the same technical calculation parameters: 10 MV photon radiation energy, VMAT irradiation technique with two full arches (0-360°), the calculation grid size was 0.3 cm, the maximum bimlet width was 0.2 cm, the maximum segment width was 1 cm (the maximum distance between opposite MLC leafs), the collimator angles for the first arc were 10° for the second arc 315°, the dose calculation was performed in the environment using the Monte Carlo algorithm for photon beams, the statistical uncertainty of the calculation was 0.8%.

In order to determine the influence of biological and physical optimization functions on the quality of radiation therapy plans with simultaneous dose escalation for prostate tumors, several therapeutic plans with different optimization functions were created for each clinical case based on dosimetric criteria: physical; biological; a combination of physical and biological functions. The dosimetric plans with biological optimization functions were used as follows: Target EUD, Serial, and Parallel. For dosimetric planning with physical optimization functions the following were used: Target Penalty, Quadratic Overdose, and a combination of these optimization functions.

Quality evaluation of the dosimetric radiation plans was based on the recommendations and protocols to predict radiation damage and select optimal dose distributions for each patient. Treatment plans were considered acceptable if the prescribed dose was greater than 95% of the volume of each treatment site (prostate, seminal vesicles, and pelvic lymph nodes). A maximum dose of 107% of the prescribed dose was allowed for <2% of prostate PTV. For OAR, dose limits were: for rectum: V74 ≤15%; V69 ≤20%; V64 ≤25%; V59 ≤35%; for bladder: V74 ≤25%; V69 ≤35%; V64 ≤50%; for femoral heads: V45 <10%. Three-dimensional dosimetric assessment of exposure plans was performed using dose-volume histograms (DVH) for target and risk organs, and conformal index (CI) and homogeneity index (HI) dose distribution for target coverage was assessed for each case.

Results. The dosimetric VMAT-SIB radiotherapy plans developed using biological, physical optimization functions and their combination were clinically acceptable in terms of target volume coverage and dose exposure to the organs at risk. The dose distribution in the clinical target volume for all VMAT-SIB plans was in the range of at least 95% of the prescribed dose covered at least 95% of the target volume. Radiation exposure levels to critical organs did not exceed tolerated levels, recalculated with consideration of fractionation

mode and radiobiological parameters. The result of absorbed dose distribution in the pelvic region using biological optimization functions obtained for one patient is shown in Figure 1.

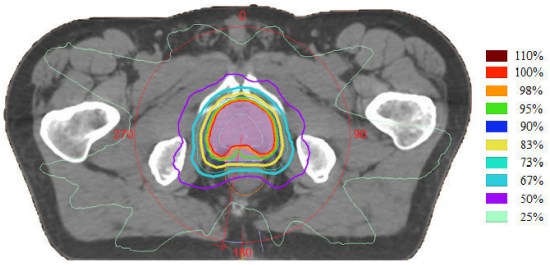

Fig. 1. Distribution of absorbed dose in the pelvic region using biological optimization functions

Figure 2 shows the results of comparing the DVHs for the irradiation target and critical organs using biological and physical optimization functions.

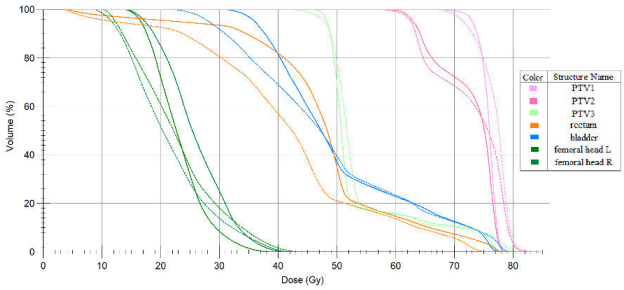

Fig. 2. Results of the comparison of DVHs for target radiation and critical organs using biological and physical optimization functions (—— physical functions; ----- biological optimization functions)

In dosimetric intensity-modulated radiotherapy planning using only biological optimization functions, critical organs receive a lower dose relative to the plan where only physical functions were used. With biological optimization functions, the volume of the rectum that receives a 40 Gy dose is reduced by 25% ($V_{40\ physical}$ = 82%; $V_{40\ biological}$ = 57%). However, the conformality index is 3% higher for the planned PTV1 target volume when using only the physical optimization functions compared to the plan where only the biological optimization functions were used ($CI_{physical}$ = 0,988; $CI_{biological}$ = 0,956).

Conclusion. In dosimetric planning, optimization functions and their combinations should be carefully selected. The dose distribution results have shown that it is possible to create clinically acceptable dosimetric plans when only biological or physical optimization functions are used separately. However, the most optimal dosimetric plan is achieved by using a combination of biological and physical optimization functions.

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