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RADIATION ONCOLOGY OPHTHALMIC CENTER BASED ON THE C-80 ACCELERATOR AT THE NRC "KURCHATOV INSTITUTE" – PNPI

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Abstract

The greatest opportunities for the treatment of intraocular tumors are provided by proton radiation therapy. With such treatment, tumor resorption is achieved in 98% of cases, and the function of vision (to one degree or another) is preserved in 70% of patients.

The article gives an overview of the technological stages of proton radiation therapy for intraocular tumor and results of cooperation between NRC "Kurchatov Institute" - PNPI and NRC "Kurchatov Institute" - ITEP are used in the implementation of the technology to develop a PRT oncophtalmologic complex based on cyclotron C-80 NRC "Kurchatov Institute" - PNPI.

THE MAIN STAGES OF PROTON RADIATION THERAPY OF INTRAOCULAR TUMORS

Radiation therapy, especially proton radiation therapy, is a complex process that requires vast hardware, software and information resources at every stage of treatment:

- diagnosis;
- surgery to document tumor extension and placement of fiducial markers;
- simulation and radiographic measurements of markers;
- treatment planning;
- fabrication of individual collimators and bolus;
- positioning;
- radiotherapy (4-5 fractions);
- follow-up.

DIAGNOSIS

The primary symptom with which patients visit an ophthalmologist is a reduced/disturbed vision.

Intraocular tumors can be diagnosed by various methods. For the primary diagnosis, a fundus camera is used, and the images of the eye are examined (Fig. 1). Computed and magnetic resonance imaging are also used. The most accurate determination of the size of a malignant neoplasm is carried out by ultrasound.

SURGERY TO DOCUMENT TUMOR EXTENSION AND PLACEMENT OF FIDUCIAL MARKERS

Eye is sufficiently homogeneous medium and tomographic data is not enough to accurately differentiate the structures of the eye and tumor. Anatomical structure of the eye [1-5] requires special diagnostic and surgical preparation for irradiation. At the same time, conventional computed tomography is of little use because of the mobility of the eye, the small size of the irradiated structures and the increased requirements for the resolution of the equipment [6,7]. Usually, in case of uveal melanoma, the tumor grows to the center of the eye (pos. 6 Fig. 2), and the vitreous mass is inert and is not included in the tumor process.

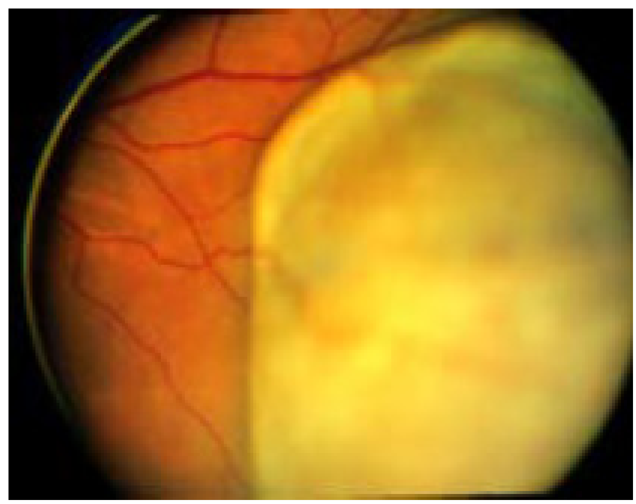

Figure 1: A snapshot of fundus chamber of the fundus with a intraocular tumor.

The main task of the stage is to define the boundaries of the base of the tumor and filing to the sclera of the eyeball, along the contour of the base of the tumor of the radiopaque clips (pos. 7 Fig. 2). To do this, a series of surgical manipulations with the eye. The eye is turned in the orbit to access the base of the tumor and illuminated so that the tumor casts a shadow on the sclera of the eyeball. And on the contour of the shadow, the surgeon hemmed tantalum clips. Based on the results of stapling the clips, the surgeon draws up a clinical protocol in which he enters data on the distance between the clips and their coordinates relative to the structures of the eye.

SIMULATION AND RADIOGRAPHIC MEASUREMENTS OF MARKERS

The main goal of the radiation simulation stage is to clarify the coordinates of the radiopaque clips and to check the mechanical properties of the eye for comfortable turning angles.

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After the recession of inflammatory processes of the surgery, the patient is going through a radiation simulation. This stage is performed in the center of proton radiation therapy directly on the radiation installation where the treatment will be performed. Individual immobilization means, such as a dental cap and a thermoplastic mask, are made for the patient.

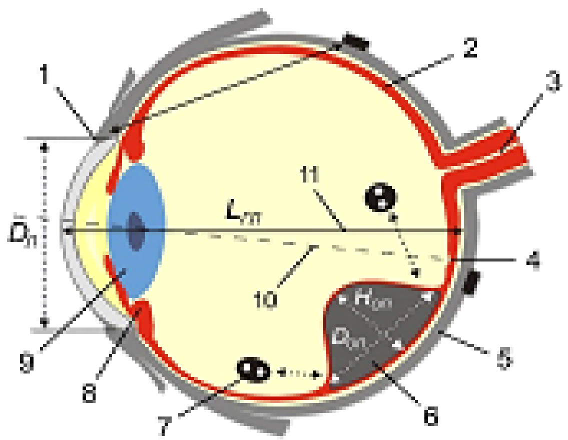

Figure 2: Anatomical structures of the eye [8,9].

According to the results of the manufacture of individual means of immobilization, the patient is placed in the chair of the positioner of the radiation installation and the medical staff immobilizes it and approximate positioning in the coordinate system of the radiation facility. After fixing the patient's eye in the desired position, two X-rays are taken using the X-ray positioning system. By processing the received X-ray images, the clinical data on the position of the radiopaque clips are clarified.

TREATMENT PLANNING

Planning proton irradiation of intraocular tumors has its own characteristics, which does not allow the use standard approaches. The eye, as already noted, is a fairly homogeneous medium, and according to the tomographic data it is difficult to accurately differentiate the structures of the eye and the tumor.

Due to these circumstances, a reconstructed anatomical model of the eye, the parameters of which are set according to clinical data measured by ophthalmologists at the stage of diagnosis and the preparation of a clinical protocol, has to be applied to radiation planning.

The main task of treatment planning is the formation of the dose distribution of the conformal target, with the average lateral margin relative to the clinical target volume taken at 2 mm, and the distal target 2.5 mm. Also, treatment planning allows us to determine the optimal position of the eyeball, in which we will minimize the effect of radiation on critical structures (Fig. 3).

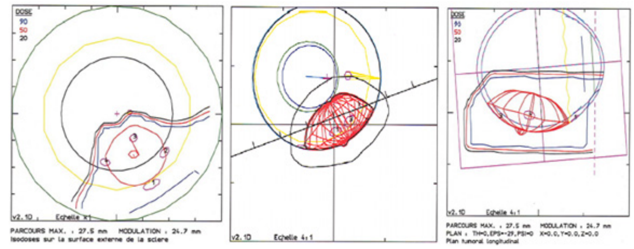

Figure 3: EyePlan dose-anatomical planning system.

FABRICATION OF INDIVIDUAL COLLIMATORS AND BOLUS

According to the results of treatment planning, individual means of forming a dose field are made, such as a finishing collimator, a bolus, and a Bragg curve modifier.

The aperture of the collimator corresponds to the cross section of the target when looking at the beam. The shape of the periodic elements of the modifier of the Bragg curve is selected and fabricated so that the transformed energy spectrum of the beam (some of the particles passing through the "teeth" of the filter slow down more than the particles passing through the "hollows" of the filter) provided the desired modification of the Bragg curve. And finally, the bolus of an individually selected form compensates for the curvature of the tumor surface (target) in such a way as to stop all particles at the rear border of the target.

POSITIONING

In radiation therapy, the goal of positioning a target is the exact alignment given in the dose-anatomical planning of the dose distribution and irradiation of the target.

The procedure of positioning and orientation of the patient's eye before irradiation of intraocular tumor can be divided into three stages:

1. Patient is placed in such a way that the center of the patient's eye is located in the pole of the beam installation, and the centers of the eyeballs should be on the same horizontal line, located in the vertical perpendicular to the axis of the beam plane;
2. moving the target to the position foreseen in the irradiation plan;
3. linear and angular corrections after the end of the second stage and X-ray (using clips) checking the position of the target.

To perform each stage of positioning, it is necessary to adhere to a specific algorithm of linear and angular displacements of the head and eye, to control which devices such as fixing point, laser positioning system, x-ray positioning system are used. The placement of the patient's geometric center at the pole of the beam unit is performed using a laser positioning system.

The second stage is performed by voluntarily directing the gaze to the fixation point established according to the irradiation plan to the required place.

Figure 4 in 2D format shows the meaning of this procedure - the direction of the patient's gaze at the fixation point.

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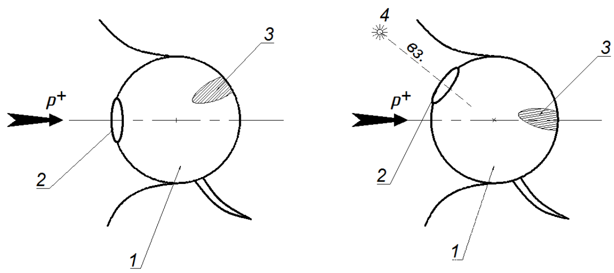

A B

Figure 4: Diagram of a voluntary change in the direction of the patient's gaze (2D format). 1 – eyeball; 2 – pupil; 3 – Intraocular tumor; 4 – Fixation point; p+ – axis of the proton beam; B3 – direction of gaze; A – eye position and tumor before changing the direction of gaze; B – eye position and tumor after a given change in gaze direction.

For verification of the irradiation plan and control of the positioning procedure, frontal and lateral X-ray images of the eyeball are taken. Radiocontrast clips stitched along the base of the tumor on the sclera of the eye should take the planned places on the X-ray photographs (Fig. 5).

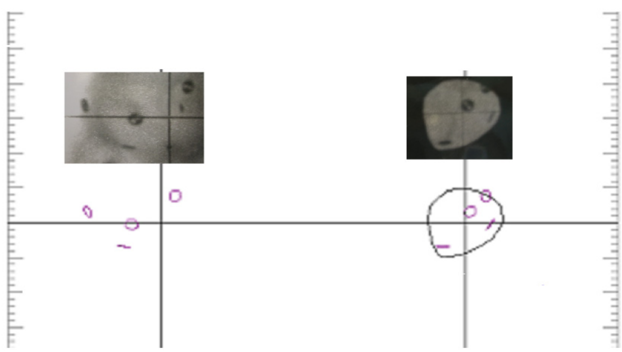

Figure 5: Comparison of X-ray images with virtual X-ray images obtained at the stage of dose-anatomical planning.

If the X-ray images do not coincide with the plan data, a repeated (specifying) planning and / or positioning procedure is required. It usually takes about three to four iterations.

RADIOTHERAPY

For proton radiation therapy in oncophthalmologic patients, a proton beam with an energy range of 60 MeV (range 3 g/cm^2) to 100 MeV (range 7.7 g/cm^2) is used. Making sure that the position of the radiopaque clips on the x-ray images is in accordance with the position specified in the irradiation plan, they proceed to the irradiation stage.

Irradiation is divided into fractions, on average for oncophthalmological patients into 4-5 fractions. Directly irradiation for a fraction takes several tens of seconds, during which the prescribed dose is collected in the target, averaging about 12-15 Gy.

RESEARCH ONCOPHTHALMOLOGICAL COMPLEX OF PROTON RADIATION THERAPY BASED ON THE CYCLOTRON C-80

The hardware, software and physico-technical support for all technological stages of proton radiation therapy for intraocular tumor listed above are implemented in the framework of the joint work of the NRC "Kurchatov Institute" - PNPI and the NRC "Kurchatov Institute" - ITEP to create a research oncophthalmological complex of proton radiation therapy based on accelerator C-80.
Main technical parameters of the Complex:

- proton beam energy 70 MeV;
- proton beam intensity 5x10^{10}p/s;
- passive beam delivery system;
- maximum dose field of irradiation 50mm;
- localization: intraocular tumor, tumor of the orbit of the eye;
- bandwidth of 400 people per year.

Composition of the Complex:

- Chair positioner;
- beam delivery system;
- patient positioning system;
- X-ray positioning system;
- treatment planning system

CONCLUSIONSE

Proton radiation therapy is one of the main and successful ways of treating eye tumor.
Realization of NRC "Kurchatov Institute" - PNPI research project to develop an oncophthalmological complex of proton beam therapy will provide high-tech care for oncophthalmological patients in the whole North-West region of Russia.

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