Radiation Physics and Chemistry 149 (2018) 104–109

Contents lists available at ScienceDirect

Radiation Physics and Chemistry

journal homepage: www.elsevier.com/locate/radphyschem

Evaluation of dose profiles using Gafchromic EBT3 films in Leksell Gamma Knife 4C around inhomogeneities in the treatment of pituitary adenoma in anthropomorphic heterogeneous head phantom

M. Najafi[a], A. Shirazi[a], Gh. Geraily[a,*], M. Esfahani[c], J. Teimouri[b]

[a] Medical Physics & Biomedical Engineering Department, Tehran University of Medical Sciences, Tehran, Iran
[b] Iran Gamma Knife Center, Tehran, Iran
[c] Imam Khomeini Hospital, Tehran University of Medical Sciences, Tehran, Iran

ARTICLE INFO

Keywords:
Gamma knife
Heterogeneous phantom
EBT3 film
Pituitary adenoma

ABSTRACT

Purpose: The Leksell Gamma Knife is a complete system for radiosurgery. Treatment dose planning of Gamma Knife assumes the human head as a homogenous media; thus received dose by target tissue and organs at risk may be lower or higher than predicted dose. Our main interest is to compare measured dose profiles in an anthropomorphic heterogeneous head phantom by EBT3 films with calculated dose by Leksell Gamma Plan.
Methods: An adult head phantom with size, shape and inhomogeneity the same as an adult human head was constructed. Then dose profiles across from isocenter and organs at risk were measured by EBT3 films and compared with those predicted by Leksell Gamma Plan.
Results: Our findings indicate that when isocenter placed at the target tissue near the frontal sinus cavity, overestimation and underestimation of the dose value affect the dose profiles. In some points of organs at risk, measured dose is more than calculated dose. Comparison of isodose curves near air-tissue interface shows that in higher isodose levels, dose perturbation is more seen. Distance to Agreement parameter for some isodose lines exceeds the total positioning error for Gamma Knife (± 2 mm). Also dose differences are more than numerical accuracy in dose delivery for stereotactic radiosurgery (± 5%).
Conclusions: Inhomogeneities in head impress dose distributions. Ignorance of inhomogeneities can cause the parts of target tissue receive under dosage and also in some points, organs at risk receive more dose. Results of this study are closer to reality because of anthropomorphic heterogeneous head phantom.

1. Introduction

Stereotactic radiosurgery (SRS) is a technique for treating lesions, typically intracranial, most often with a single high dose of ionizing radiation (Moskvin et al., 2004). An example of SRS is the Gamma Knife. The Leksell Gamma Knife (LGK) model 4C manufacturing by Elekta consists of 201 collimated cobalt 60 sources arranged over a hemispherical surface. Narrow beam of any source accumulates at the center of the hemisphere to reach the target in the brain. The treatment is obtained by delivering prescribed dose of radiation (Zhu et al., 2010).

Pituitary adenoma is a relatively common tumor, comprising approximately 10–20% of all intracranial lesions that are divided into two categories: functional and nonfunctional tumor. Treatment of pituitary adenoma with Gamma Knife radiosurgery because of the ability of this technique to deliver the full treatment dose within one section and reducing risk of injury to nearby neural structure, immediately became popular (Kim et al., 2012).

The median prescribed dose for functional and nonfunctional pituitary adenoma is 20 Gy (12–28 Gy) and 12.5 Gy (9–15 Gy), respectively (Castro et al., 2010). Organs At Risk (OAR) that stay on proximity of pituitary gland are optic nerves, optic chiasm and brain stem that should be saved in the treating by ionizing radiation (Iwata et al., 2011). For patient who received dose by optic nerve and chiasm are less than 10 Gy, incidence of neuropathy is zero and for received dose more than 10 Gy to the structure of visual pathway, incidence of neuropathy increases (Leber et al., 1998).

Leksell Gamma Plan (LGP) is a treatment dose planning system designed to calculate the dose distribution of the LGK. LGP by adding data corresponding to each one of the 201 beams, calculates the dose distributions. The treatment planning system (TPS) version 5.34 in Gamma Knife model 4C assumes the human head as a homogenous media (Water equivalent) and tissue heterogeneities such as air and

* Corresponding author.
E-mail address: gh-gerally@sina.tums.ac.ir (G. Geraily).

https://doi.org/10.1016/j.radphyschem.2018.04.003
Received 18 September 2017; Received in revised form 2 March 2018; Accepted 3 April 2018
Available online 05 April 2018

bone and any perturbation due to these inhomogeneities are not taken into account (Al-Dweri et al., 2005; Isbakan et al., 2007; Moskvin et al., 2004). In the vicinity of bone-tissue or air-tissue, absence of electronic equilibrium occurs and affects dose distributions near the interface. Thus delivered dose to some points may be lower or higher than calculated dose by LGP (Moskvin et al., 2004). Optic tract and pituitary gland are adjacent to air cavity (Ethmoidal sinus). The pituitary gland is placed in Sellar Torsica which is a part of sphenoid bone (Gray, 2006). Since the prescribed dose for treating functional and nonfunctional pituitary adenoma are within 9–28 Gy and organs at risk such as optic tract and chiasm and also pituitary gland are adjacent to heterogeneities, received dose by organs at risk may be higher than tolerance dose and results in damage them. Also received dose to target (Pituitary tumor) may be lower than calculated dose so prescribed dose is not delivered to the target. Some studies investigated the effects of inhomogeneity on dose distribution in inhomogeneous phantom in Gamma Knife (Al-Dweri et al., 2005; Isbakan et al., 2007; Moskvin et al., 2004; Pourfallah et al., 2009a; Pourfallah et al., 2009c; Watanabe et al., 2005). These studies assumed the head as a sphere. Also for the heterogeneity in these studies, several media such as aluminum, Poly Tetra Fluoro Ethylene (PTFE) and air with a simple shape (cubic or spherical) were considered. In this way, differences between calculated and measured dose around the inhomogeneous media were obtained. There are no results published on the impact of inhomogeneity on dose distributions and delivered dose to organs at risk and target tissue in an anatomically realistic adult head phantom by the LGK. In this study, an adult head phantom with similar size, shape and inhomogeneity with the same as an adult human head was used (Najafi et al., 2017b). Then received dose by organs at risk and target tissue were measured by Gafchromic EBT3 films and compared with calculated dose by LGP. The main purpose of this paper is to investigate dose differences between measured and calculated data by LGP in a heterogeneous head phantom.

2. Methods and materials

2.1. Gafchromic EBT3 film calibration

To measure dose rate at Unit Center Point (UCP) of LGK 4C, an ion chamber PTW 31010 was placed at the center of an Acrylonitrile Butadiene Styrene (ABS) spherical plastic phantom that is used for quality assurance in Gamma Knife. Also the American Association of Physicist in Medicine's (AAPM) task group 51 protocol with a correction factor that adapt this protocol to the small and nonstandard fields was used (Alfonso et al., 2008). By applying pressure and temperature correction factors, a traceable calibration factor and correction factor for small and nonstandard fields, absolute dose rate at UCP was obtained.

For calibration of Gafchromic EBT3 films, sheets of these films with size of 8″ × 10″ were used. According to the scan handling guide of EBT3 film, samples of film were cut into square pieces of 5 × 5 cm^2. Because all sample should be scanned at the same orientation, any pieces were marked at the top of films (Products, 2012). For irradiation samples of EBT3 film, LGK model 4C with ABS phantom was used (Elekta, 2004; Najafi et al., 2017a). After placing any sample of EBT3 films in special cassette in ABS phantom, irradiation was done for dose ranging from 0 to 40 Gy three times. 48 h after irradiation, any pieces of films was scanned with Micrtotek Scan Maker 9800XL and saved in TIFF format (Sim et al., 2013; Sorriaux et al., 2013). Saved images were analyzed with ImageJ software (Rasband, 2014) and Net Reflective Optical Density (Net ROD) was calculated with the following formula:

$$\text{Net ROD} = \log (I_u/I_i) \tag{1}$$

where I_u and I_i are the average pixel values of the reflected intensities through non irradiated and irradiated films respectively (Farah et al., 2014).

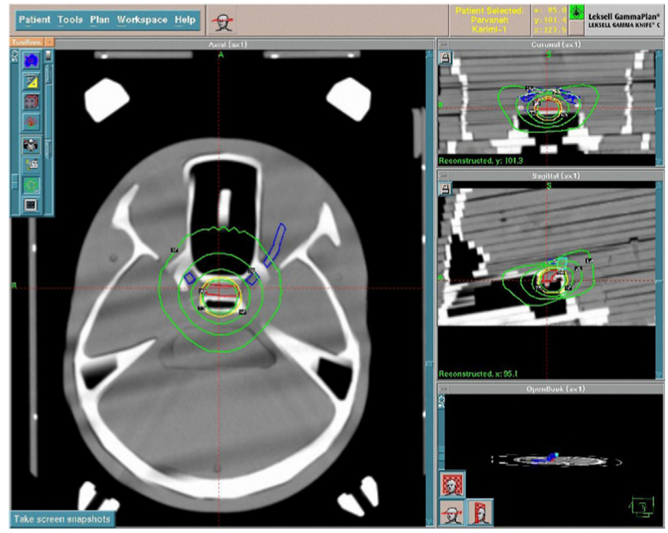

Fig. 1. Treatment planning for functional pituitary adenoma.

According to the scan handling guide of EBT3 film, for dose ranging from 0 to 10 Gy and 10–40 Gy, dose response calibration curves were plotted at red and green color channel, respectively (Products, 2012).

2.2. Irradiation of heterogeneous head phantom

To measure delivered dose a constructed anthropomorphic heterogeneous head phantom was used (Najafi et al., 2017b). EBT3 films were cut into similar shape of layers. One piece of film was placed between layers that contain Optic nerve, brain stem and pituitary gland and another piece of film was placed three layer higher that contain chiasm. To prevent disturbance in delivered dose to the target, the film was cut in air cavity level.

After fitting EBT3 films in the phantom, stereotactic frame was fixed to it and CT images were taken and imported to LGP. First, optic nerve, chiasm, brain stem and pituitary gland were contoured. Then with prescribed dose of 20 Gy, treatment planning was done for functional pituitary adenoma (Fig. 1).

Heterogeneous head phantom with stereotactic frame was placed in the LGK 4C unit and irradiation was done (Fig. 2). After irradiation, EBT3 films were removed from the phantom and after 48 h scanned with Microtek ScanMaker. Analyzing of irradiated EBT3 films was done with ImageJ software.

After scanning the irradiated EBT3 films, dose profiles at the isocenter and organs at risk such as optic nerve, optic chiasm, brain stem and also near the air and bone inhomogeneity were plotted. A 3D coordinate system was considered which X, Y and Z axes have been shown in Fig. 3. Dose profiles at isocenter were plotted along X and Y axes at Z = 123.5 in LGP (the TPS considers a coordinate system based on stereotactic frame and each point was related to a specific coordinate.) For EBT3 films, measured dose profiles were plotted in MATLAB software (Guide, 1998). Also dose profiles in optic nerve, brain stem and air and bone inhomogeneities were plotted at Z = 123.5. To draw dose profiles in the chiasm, the EBT3 film was placed a few layers above the optic nerve and dose profile was plotted at Z = 113.5. According to Fig. 3, dose profiles at isocenter were plotted along arrows 1 and 2 and for organs at risk (i.e. optic nerves, brain stem and optic chiasm) were plotted along arrows 3, 4 and 7 respectively. Also dose profiles in air and bone inhomogeneity were plotted along arrows 5 and 6.