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Technical Notes

Radiation dose to the fetus during CyberKnife radiosurgery for a brain tumor in pregnancy

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ABSTRACT

Purpose: Pregnancy during radiosurgery is extremely rare in clinical practice. We report fetal dose results during CyberKnife radiosurgery for a brain tumor in pregnancy.
Methods and materials: A 26 year old pregnant woman with a rapidly growing deep-seated grade-III glioma was treated during the third trimester of gestation using CyberKnife. Ultrasound imaging was used to determine the position of the embryo prior to treatment. A dose of 1400 cGy was prescribed aiming to control tumor growth until delivery of the child. Prior to radiosurgery, the treatment was simulated on an anthropomorphic phantom. Radiation dose to the embryo was measured using a Farmer chamber and EBT3 films.
Results: Fetal doses of 4.4 cGy and 4.1 cGy were measured for the embryo's head and legs, lying at 56 cm and 72 cm from the isocenter, respectively, using the Farmer chamber situated at 8.5 cm depth beneath the phantom surface. Dose results of 4.4 cGy, 3.5 cGy and 2.0 cGy were measured with the films situated at depths of 6.5 cm, 9.5 cm and 14.5 cm, respectively. An average dose of 4.2 cGy to the fetus was derived from the above values. A corresponding dose of 3.2 cGy was also calculated based on results obtained using EBT3 films situated upon the patient skin.
Conclusions: The measured fetal doses are below the threshold of 10 cGy for congenital malformations, mental and growth retardation effects. The radiogenic cancer risk to the live-born embryo was estimated less than 0.3% over the normal incidence. The treatment was administered successfully, allowing the patient to deliver a healthy child.

Introduction

The incidence of malignant brain tumors during pregnancy is rare, ranging between 0.025‰ and 0.05‰ [1,2]. In treating a pregnant woman with a malignant brain tumor, surgical resection and decompression should be performed as soon as possible if the tumor is large and causing progressive symptoms or surrounded by edema that is causing considerable mass effect. If the tumor is not producing much mass effect and the patient is clinically stable any invasive procedure can be postponed until after child delivery [3]. In the meantime, careful monitoring using frequent neurological examinations and neuroimaging studies should be performed. In case of tumors located in deep or eloquent brain regions where radiotherapy and/or chemotherapy is in order, a careful balance between the mother's benefit and the fetus risk should be performed [4,5]. As far as radiotherapy is concerned, radiation exposure in utero is associated with an increased risk of multiple severe complications, including lethality, malformations, mental and/or growth retardation, as well as cancer induction [6–8]. These effects have been reviewed in two reports by the International Commission on Radiological Protection and depend on pregnancy stage and the absorbed fetal dose [9,10].

In brain tumor radiotherapy, fetal dose is due to radiation leakage from the linear accelerator (linac) head, the scattered radiation from the beam collimation systems, the flattening filter and wedges (if applicable), as well as the scattered radiation from the patient body [11]. In contemporary radiotherapy techniques, like Intensity

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Modulated Radiation Therapy (IMRT) and Stereotactic Radiosurgery/Radiotherapy (SRS/SRT), the dose delivered to the tumor and surrounding organs at risk (OARs) is optimized using an increased number of intensity modulated small radiation beams utilized by specifically designed collimation systems. While these techniques are capable of creating conformal and steep spatial gradient dose distributions, introducing a paradigm shift in radiotherapy, they are associated with an increased number of Monitor Units (MUs) and consequently an accountable peripheral dose [12,13]. Moreover, the aforementioned techniques are usually combined with image guidance subsystems to ensure accurate registration of the planned dose distribution with the treated lesion. In case x-rays are used for guiding treatment delivery, the additional dose to the fetus from this procedure should also be considered [14].

In this work, we describe dosimetry measurements performed for a pregnant patient with a deep-seated malignant brain tumor treated in our clinic using the CyberKnife™ (Accuray Inc. Sunnyvale, CA, USA) stereotactic radiosurgery system [15,16].

Methods

Patient details

The presented case involves a 26 year old female who developed sudden headache with nausea and vomiting during the 13th week of pregnancy. The patient underwent CT and MR scans that that showed a 2.5 cm of maximum dimension (~4.2 cm^3) lesion located deeply in the right posterior hemisphere close to the occipital horn of the lateral ventricle, and a severe tetraventricular bleeding. A stereotactic brain biopsy was carried out which revealed a high-grade glioma (WHO grade III). The patient was offered the option of pregnancy cessation and subsequent surgery or to postpone surgery until delivery and perform a closer follow up using serial imaging. Due to the patient's wish to deliver her child and as her mental capacity was intact, surgery was deferred. A subsequent MR scan was carried out 4 weeks later and showed progressive disease with an increase of the lesion size to $(3.6 \times 3 \times 2.5)$ cm^3 and a volume of 8.7 cm^3. The rapid increase of tumor size, the challenging surgical location deep in the hemispheric white matter and the chance of repeated bleeding, together with the absolute refusal of a therapeutic abortion, posed indeed a grim prognosis quoad vitam to both mother and child.

CyberKnife radiosurgery was then considered as an alternative to achieve tumor growth control until delivery. Ultrasound imaging was performed to determine the position of the embryo prior to radiosurgery. The distance of the embryo's head and legs from the midline of the patient's head was measured equal to 56 cm and 72 cm respectively. Radiosurgery preparation included the construction of a customized thermoplastic mask of the patient's head in treatment position and acquisition of a contrast enhanced CT scan with 0.1 cm slice thickness and 0.1 cm slice separation, using a 256-multi-slice SOMATOM Definition Flash CT scanner (Siemens AG, Erlangen, Germany). While the dose to the fetus from a head CT scan has been reported to deliver a dose of less than 5×10^{-4} cGy [9] to the fetus, a 0.2 cm thick shielding apron was positioned around the abdomen of the patient. An additional set of 0.1 cm isotropical resolution T1- and T2-weighted axial MR images of the patient's head was also acquired using a 3T MAGNETOM Trio scanner (Siemens), to aid delineation of the target and surrounding OARs. All image series were imported into the MultiPlan™ Treatment Planning System (TPS) (Accuray). The anatomical MR images were registered with the CT volume using the registration algorithm of the TPS. The target and the critical structures of the brain (i.e., brain stem, optic chiasm and optic nerves) were delineated using the CT and the fused anatomical MR images. Both eyes were also contoured and used as blocking structures (i.e., avoid beam direction passing through them) in treatment planning. The TPS sequential optimization tool was used to create a conformal treatment plan with optimum tumor coverage, maintaining minimal: the dose to surrounding healthy brain tissue, OARs and total MUs.

Fetal dose measurements

Dose measurements were performed using the RANDO™ anthropomorphic phantom (The Phantom Laboratory, Salem, NY). The specific phantom is constructed with a natural human skeleton, which is cast inside soft tissue simulating material. Lungs are molded to fit the contours of the natural rib cage. The phantom is sliced at 2.5 cm intervals. The intervals comprising the abdomen of the RANDO phantom were replaced with RW3 (PTW, Freiburg, Germany) slabs of (30×30) cm^2 lateral dimensions and 20.5 cm total thickness (Fig. 1). A 0.6 cm^3 PTW-30013 Farmer ionization chamber was placed at 8.5 cm depth beneath the surface of the phantom using an appropriate drilled RW3 slab. Besides the ion chamber, the dose to the fetus was also measured using Gafchromic EBT3 films (ISP, Wayne, NJ). Three (20.3×25.4) cm^2 sheets of EBT3 films were positioned between the RW3 slabs at depths of 6.5 cm, 9.5 cm and 14.5 cm (Fig. 1). Two additional sets of three (3×3) cm^2 EBT3 films were positioned 56 cm away from the isocenter on the surface of the RW3 phantom and the patient, respectively, for surface dose measurements and verification purposes.

Film dosimetry was performed according to the protocol suggested by Devic and colleagues [17]. The calibration curve of the used film batch was obtained beforehand by irradiating two sets of 15 pre-cut (3×3) cm^2 EBT3 films situated 1.5 cm beneath the surface of a 20 cm thick RW3 phantom, with doses in the range of 0 cGy–300 cGy using the 6 cm in diameter CK reference beam. Absorbed doses to the films were measured using a Farmer chamber situated at 10 cm depth inside the RW3 phantom. All EBT3 films were scanned one day post irradiation to allow post irradiation optical density growth, using an Epson Expression 1680Pro flatbed optical scanner. The scanner was used in transmission mode and all films were scanned in 48-bit RGB mode with a resolution of 72 dpi, but only the red color channel of the image was used. It is noted that film dosimetry was performed using the red channel of the scanned images since for the dose range of interest the sensitivity (defined as net optical density (netOD) change per unit absorbed dose) of the EBT dose–response is the higher compared to the corresponding sensitivity for the green and blue channels [18]. All films were placed in the same area of the scanner bed, maintaining the same orientation throughout the scanning procedure. Custom written routines were employed to obtain the net optical density (OD) of each film on a pixel by pixel basis and to convert

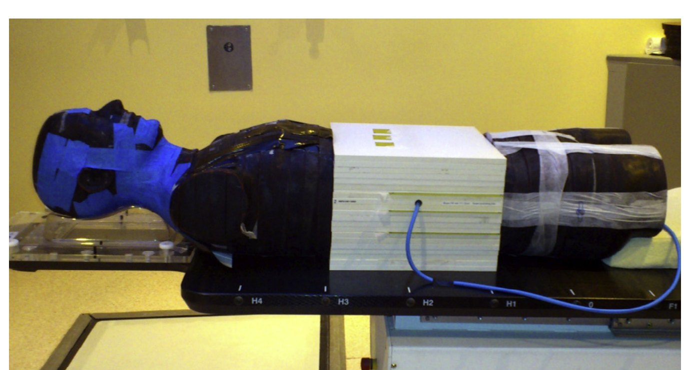

Figure 1. A photograph of the anthropomorphic phantom used to measure the dose to the fetus.