Radiosurgery for cerebral arteriovenous malformation during pregnancy: A case report focusing on fetal exposure to radiation

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Introduction: We present the case of a pregnant woman who underwent linear accelerator (LINAC)-based stereotactic radiosurgery (SRS) and we discuss the fetal exposure to radiation.

Clinical Presentation: A 20-year-old woman at 18 weeks of gestation presented with right cerebral hemorrhage and underwent urgent evacuation of the hematoma. She recovered well after surgery, but cerebral angiography after the surgery revealed a small deeply seated arteriovenous malformation (AVM) in the right frontal lobe extending to the right basal ganglia.

Methods and Results: We examined the diffuse AVM and treated it with LINAC-based SRS at 24 weeks of gestation. Before SRS, the fetus was exposed to a radiation dose of 8.26 mGy, which was estimated by conducting an experiment using an adult RANDO phantom, and a radiophotoluminescent (RPL) glass rod dosimeter (GRD) system. The patient underwent Caesarean delivery at 36 weeks of gestation and gave birth to a healthy baby.

Conclusion: The exposure of fetus to radiation during SRS was exceedingly low. SRS can be used as an alternative treatment to microsurgery for resolving small deeply seated AVMs even in pregnant patients.

Keywords: cerebral arteriovenous malformation, linear accelerator-based stereotactic radiosurgery, pregnancy, fetus exposure to radiation

Introduction

Stereotactic radiosurgery (SRS) delivers a high-energy ionizing radiation dose focused on a stereotactically defined intracranial target in a single fraction with high spatial accuracy. SRS is now considered as a minimally invasive alternative technique to microsurgery for cerebrovascular malformations, benign and malignant brain tumors, particularly in cases of small and surgically inaccessible lesions. However, it is necessary to evaluate the radiation exposure to extracranial sites in patients who undergo SRS. Especially, fetal exposure to radiation in pregnant patients should be carefully investigated because radiation can affect normal fetal development. It remains to be determined whether SRS is a clinically safe method for the treatment of pregnant patients suffering from brain disorders when surgical or conservative treatments are not acceptable or possible.

Herein, we present the case of a pregnant woman who underwent linear accelerator (LINAC)-based SRS for a ruptured arteriovenous malformation (AVM) in an eloquent area, which was performed after determining the fetal exposure to radiation in a phantom experiment.
Case presentation

A 20-year-old woman at 18 weeks of gestation suddenly collapsed and was transferred to our stroke center. Computed tomography (CT) scans showed a large intracerebral hemorrhage in the right frontoparietal lobes (Figure 1). On admission, she already had anisocoria of pupils (right side: Ø6.0mm, left side: Ø1.5mm) due to impending cerebral herniation. So, craniotomy was performed immediately for the evacuation of the intracerebral hematoma without investigating further for the cause or the origin of the bleed. Bleeding source could not be detected during the operative procedure. After surgery, she showed good recovery and the fetus was normal. At 16 days after surgery, she regained consciousness and underwent conventional cerebral angiography with lead sheets to reduce the fetal exposure to radiation and her right internal carotid angiograms revealed a deeply seated small frontal AVM with a maximum diameter of 21 mm extending to the basal ganglia (Figure 2). On the basis of the angiographic findings, we interpreted that the nidus of AVM was non-compact and was intervening the brain parenchyma (diffuse AVM). This case was discussed at a multidisciplinary treatment planning conference. Surgical resection was not recommended due to the risk of neurological deficits. Further, conservative treatment had a risk of subsequent hemorrhage and was bound to be associated with high maternal mortality rates. Finally, SRS was recommended if the irradiation to the inner pelvis could be kept exceedingly low in order to avoid any damage to the fetus.
SRS planning

Before SRS was performed, we assessed the fetal exposure to radiation by the LINAC (MEVATRON 77DX67, Siemens Medical Solutions USA, Inc., Concord, CA, USA) which delivered 10 MV X-ray beams at multiple noncoplanar converging arcs, by using an adult RANDO phantom (Alderson Research Laboratories, Inc., Stamford, CT, USA) [1] and a radiophotoluminescent (RPL) glass rod dosimeter (GRD) system (Dose Ace®, Chiyoda Technol Corporation, Tokyo, Japan) [2].

The RANDO phantom and the RPL-GRD systems are briefly described below. The RANDO phantom is composed of a genuine human skeleton embedded in a mass with the properties of human soft tissue (effective atomic number \( Z_{eff} = 7.3 \); mass density \( \rho = 0.985 \text{ g} \cdot \text{cm}^{-3} \)) and is of the average female size (height, 163 cm; weight, 54 kg). The RPL-GRD system is composed of readout equipment with the standard dosimeter and small one-element silver-activated metaphosphate glass detectors. The weight composition of GRD is as follows: 31.55% P, 51.16% O, 6.12% Al, 11.0% Na, and 0.17% Ag (\( Z_{eff} = 12.039; \rho = 2.16 \text{ g} \cdot \text{cm}^{-3} \)). The GRD is 8.5 mm (GD-301) in length and has a diameter of 1.5 mm. We used the RPL-GRD system because it is known to produce a smaller standard deviation in dose measurement as compared to thermoluminescent dosimeter (TLD) [2]. We placed 6 PRL-GRDs on the abdominal surface and 9 in the pelvic region to predict the location of the uterus and the fetus (Figure 3). The irradiation to the GRD was measured after administering 20 Gy to the intracranial target in the right basal ganglia with a maximum diameter of 21 mm on the LINAC table (Figure 4). In the absence of lead sheets over the phantom’s abdomen, the average radiation doses to the abdominal surface and inner pelvis were 8.86 mGy (range, 7.98-9.80 mGy), and 5.21 mGy (range, 4.56-5.87 mGy), respectively. The fetal exposure to radiation during SRS appeared to be extremely low, and the patient and her family consented to the radiosurgical treatment.

She underwent LINAC-based SRS at 24 weeks of gestation with lead sheets placed over her abdomen to reduce the exposure to her fetus. The treatment was planned on the basis of contrast-enhanced thin-slice CT imaging data. We placed 10 RPL-GRDs between her abdominal surface and the lead sheets. Two isocenters with 12 mm and 9 mm circular collimators were used to deliver a radiation dose of 20 Gy to the lesion at 80% isodose line. The exposure angles were tailored to reduce the exposure to the abdomen. The average exposure dose to her abdominal surface in the presence of the lead sheets was 14.05 mGy (range, 13.64-14.34 mGy).

12 weeks after the SRS, the patient underwent Caesarean delivery at 36 weeks of gestation without complications. Currently, 7 years after SRS, the child’s physical and mental development is normal, and she does not have any other anomalies.
Discussion

Generally, pregnant patients with certain diseases are advised to avoid radiation therapy until post parturition because it can cause harm to the fetal development. Exposure of the fetus to radiation should be avoided, if possible, especially during the first trimester of pregnancy and to a lesser degree in the second trimester [3,4,5], because of the adverse effects of this procedure on embryos and fetuses. The adverse effects include lethality, malformations, mental retardation, growth retardation, carcinogenesis, and genetic abnormalities [4,6].

During the pre-implantation period (0-8 days of gestation), a radiation dose of 100 mGy is lethal to the embryo [7]. In the organogenesis period (2-8 weeks), the main risk of radiation dose is the malformation of organs, which frequently occurs in neonates with their mothers receiving abdominal radiation of more than 500 mGy [6,7]. During the early fetal stage (8-15 weeks), the main risks include mental retardation, microcephaly, and growth retardation, and the radiation dose threshold for these events is estimated to be 120 mGy [6]. During the mid-fetal stage (15-25 weeks), mental retardation is the main adverse effect. The radiation threshold dose during this period is between 60 mGy (8-15 weeks) and 250 mGy (16-25 weeks) [6]. In the final period of pregnancy (over 25 weeks), the risk of malformation and mental retardation becomes almost negligible. Nevertheless, there is a risk of growth retardation when radiation doses exceeding 500 mGy [6]. Concerning the risk of oncogenesis after fetal exposure to radiation, Doll et al. [9] reported that the incidence of radiation-induced oncogenesis at dose of 10 mGy in the last trimester was higher than the spontaneous incidence with a relative risk of 1.4 [10]. On similar lines, Brent et al. [7] recommended the termination of pregnancy when fetuses were exposed to radiation doses of more than 100 mGy.

Several experimental analyses on fetal exposure during SRS have been reported [3,5,6,11,12], however, there are limited clinical reports on SRS in pregnant patients. Yu et al. [14] also reported that the radiation exposure to extracranial sites in patients who underwent SRS was low, approximately 0.2% on an average of the prescribed dose for pelvis according to the requirements of the experiment. Based on our data, we confirmed that the radiation dose to the fetus during SRS was much lower than the estimated dose that caused malformation, mental retardation, and childhood carcinogenesis.

The management of ruptured AVM during pregnancy remains controversial. The treatment regimen should be carefully planned considering gestational age, patient’s condition and Spetzler-Martin grade of the AVMs [15]. When our patient suffered from ruptured AVM, her gestational age was 18 weeks, with at least 17 weeks remaining for a safe delivery. Considering the high re-bleeding rates of deeply seated AVMs (32.9% in the first year), and the maternal (28%) and fetal (14 to 26%) mortality rates, early treatment was warranted [16,17,18,19,20]. So, conservative treatment was not recommended. Surgical resection would have been better for this ruptured AVM, however, it might have subjected the patient to high risk of neurological deficits as the AVM was in the eloquent area. On such occasions, on the basis of our experiment, SRS may help physicians in the treatment of pregnant patients with deeply seated AVMs,

Conclusion

The exposure of fetus to the radiation during SRS remains exceedingly low. The exposure dose doesn’t give several radiation damages to fetuses. SRS can be used as an alternative treatment to microsurgery for managing small deeply seated AVMs even in pregnant patients.

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