Out of field dose during Gamma Knife treatment: a paediatric case study

V Moutrie[1], M Grace[1], M A Izard[1], J W Fuller[2]
[1]Genesis Cancer Care, Suite 1 Level B2, 3 Technology Place, Macquarie University, NSW 2109 Australia
[2]Macquarie Neurosurgery, Suite 201, Level 2, 2 Technology Place, Macquarie University NSW 2109 Australia

E-mail: vaughan.moutrie@genesiscare.com.au

Abstract. An 11-year-old girl with an arteriovenous malformation (AVM) was referred for Gamma Knife treatment. As this would be the first paediatric treatment in Australia, additional investigations were undertaken into out of field dose to assure the best possible long term outcome for the patient. A phantom was constructed from water equivalent materials to simulate the patient. A target volume was defined to emulate the size and location of the AVM visible in diagnostic images. An ionisation chamber and EBT3 Gafchromic film were used to record absorbed dose at strategic points both on the surface and at depth within the phantom. On the day of treatment, EBT3 Gafchromic film was used to conduct in vivo dosimetry. The pre-treatment phantom measurements matched the planning system for the cranial section (the only modelled section) and no measurable dose above background was detected in the extracranial sites. In vivo measurements of the lenses returned doses of up to 2 cGy for imaging and 8 cGy for treatment which was also consistent with the planned dose. Dose to the thyroid, chest and abdomen was not measurable above background.

1. Introduction

It is important when delivering radiation therapy that dose outside the intended target volume is kept as low as possible to reduce unwanted side effects [1]. This is especially true for stereotactic techniques, where large doses are delivered in hypofractionated or single fraction settings. Out-of-field dose minimisation is particularly important for paediatric patients for several reasons: increased consideration towards radiation induced malignancies due to long life expectancy, relatively limited information on paediatric radiobiology and, in the case of intra-cranial treatments, the generally shorter distance between the target area and radiosensitive organs.

An 11-year-old girl with an arteriovenous mal-formation (AVM) was referred for Gamma Knife treatment. Because of the considerations above, it was decided to conduct a detailed assessment into the potential delivered dose to the patient prior to proceeding with the treatment, and monitor the dose received throughout the course of the procedure.

A literature review found several previous studies [2-5] investigating peripheral doses in Gamma Knife treatment, some including paediatric cases [2, 4], however all of these studies were performed using previous generation helmet-based delivery systems that differ from the Perfexion machine at our facility and are likely to have different out-of-field dose levels. These studies used a mix of in vivo patient dosimetry and phantom measurements using ion chambers and thermoluminescent detectors.

Extracranial doses across the studies were in the order of 0-0.2 Gy. It was noted [4] that measured organ doses varied significantly based on the exact treatment conditions.

2. Methods

2.1. Preliminary study

A phantom was constructed from water equivalent materials to simulate the patient (figure 1) using self-reported physical dimensions from the patient. Calibrated ionisation chambers and EBT3 Gafchromic film were used to record absorbed dose at strategic points both on the surface and at depth within the phantom. As only surface measurements can be made in vivo, this allowed validation of measurement points on the surface as good representations of corresponding organs at depth in the same location.

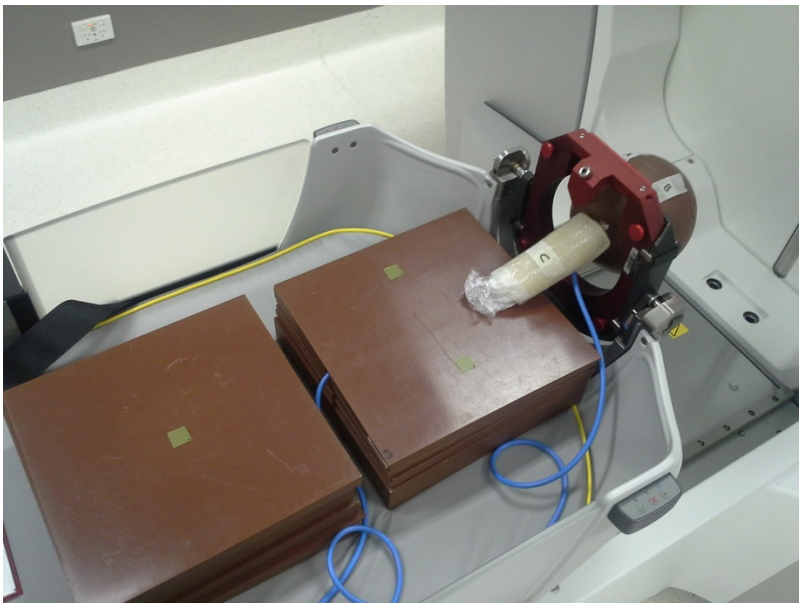

Figure 1. Configuration of the test phantom.

A spherical dosimetry phantom was used to simulate the head of the patient and computed tomography (CT) image set used to plan the mock treatment. A PTW 31010 Semiflex ion chamber was inserted to the centre of the sphere. Pieces of EBT3 film were placed in the position of the eyes. A sheet of jelly bolus was rolled into a cylinder to simulate the neck and a piece of film taped to the surface to measure thyroid dose. The remainder of the body was simulated with stacks of Solid Water sheets. A PTW 31013 Farmer ion chamber was placed at a depth of 1.5 cm in the centre of superior block to measure sternum dose. EBT3 film was placed in positions to measure breast and ovary dose both at the surface and at a relevant depth (0.5 cm and 8 cm respectively). The position of the breast/sternum was approximately 30 cm from the centre of the head and the ovary position a further 30 cm inferiorly.

A target volume was defined to emulate the size and location of the AVM visible in diagnostic images (figure 2), and a dose of 100 Gy to the 50% isodose, five-fold higher than the regular prescription, was planned to ensure adequate signal to the dosimeters. The predicted dose to the centre of the sphere was 0.6 Gy, the right eye was 1.4 Gy and the left eye 1.6 Gy. As very low readings were anticipated, background readings were measured for each ion chamber for a period of 9999 s prior to delivery and used to correct the measured reading. Film was processed according to the standard in vivo dosimetry procedure used at the facility [6].

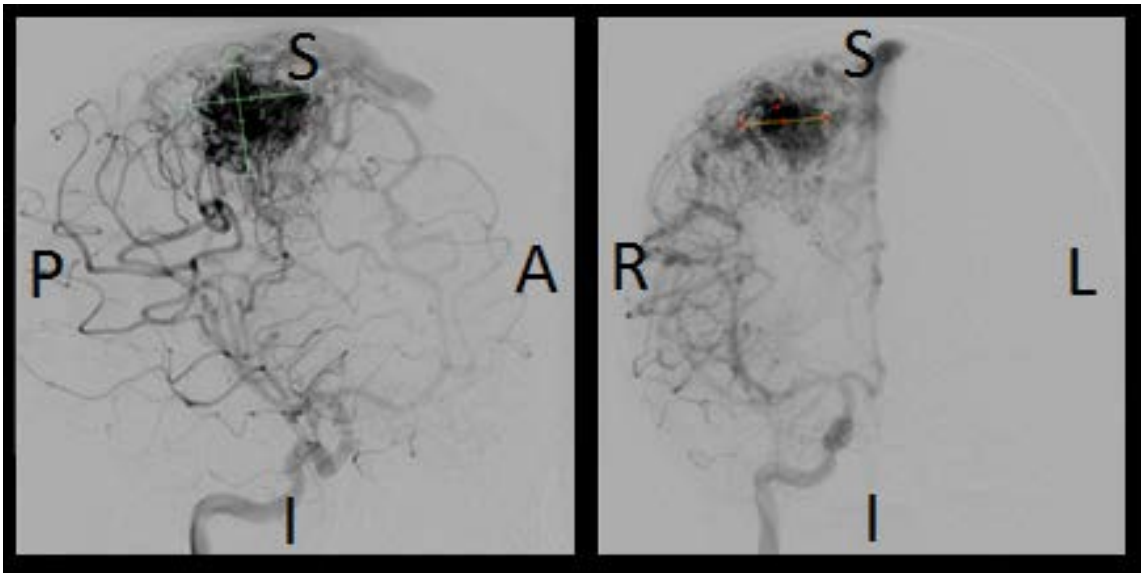

Figure 2. Location of the AVM on early diagnostic scans.

2.2. In vivo dosimetry

In vivo dosimetry was conducted on the day of treatment, separately monitoring imaging (digital subtraction angiography (DSA), CT) and treatment dose to the eyes, chest, abdomen, and for treatment only, thyroid. The treatment prescription was 20 Gy to the 50% isodose.

3. Results

Table 1. Results for the preliminary study, peak dose 200 Gy.

Dosimeter	Site	Location	Measured dose (Gy)	Planned dose (Gy)
Semiflex	Centre of head	Centre of sphere	0.5	0.6
Farmer	Sternum	Midline, 1.5 cm deep	b	n
Film A	Right eye	4 cm lat, surface	1.0	1.4
Film B	Left eye	4 cm lat, surface	1.7	1.6
Film C	Thyroid	Midline, surface	0.04	n
Film D	Right breast	10 cm lat, 0.5 cm deep	0.02	n
Film E	Left breast	10 cm lat, 0.5 cm deep	0.02	n
Film F	Right breast	10 cm lat, surface	0.03	n
Film G	Left breast	10 cm lat, surface	0.03	n
Film H	Ovary	Midline, 8 cm deep	b	n
Film I	Ovary	Midline, surface	b	n

b: Measurement was indistinguishable above background, <0.01.
n: Planned dose not available as location is outside the region bound by the stereotactic frame.

Table 2. Results for the in vivo dosimetry, peak dose 40 Gy.

Site	Imaging dose (Gy)	Treatment dose (Gy)	Planned treatment dose (Gy)
Left eye	0.01	0.06	0.1
Right eye	0.02	0.08	0.1
Chest	b	b	n
Abdomen	b	b	n
Thyroid	-	b	n

b: Measurement was indistinguishable above background, <0.01.
n: Planned dose not available as location is outside the region bound by the stereotactic frame.

4. Discussion

All extracranial measurement points showed exceedingly small dose, even under experimental conditions where an escalated prescription dose was used. Reasonable agreement between planned and measured dose was found for points within the dose calculation volume.

In vivo measurements only detected dose to the eyes, with no distinguishable dose above background for the thyroid, chest or abdomen. Dose received from the CT and DSA was just discernible at 1 cGy and 2 cGy for the left and right eyes respectively. The higher dose to the right eye is rationalised by the placement of the x-ray source on this side for lateral imaging during DSA. The right eye also received slightly higher dose during treatment due to being nearer the target volume seen in figure 2. The point dose tool in the treatment planning system reports dose to the nearest 0.1 Gy, and in the vicinity of the eyes the displayed dose varied between 0.0 Gy and 0.1 Gy. This predicted dose is therefore a match to the measured doses of 0.06 Gy and 0.08 Gy for the left and right eyes respectively to within the associated degree of uncertainty.

5. Conclusion

The rapid drop in dose outside the field was verified and measured doses to organs at risk were very small. The study demonstrates the capability of the Gamma Knife to confine high doses to the intended volume, and the accuracy of the planning system in predicting out-of-field dose.

6. References

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