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Completion of Gamma Knife Radiosurgery for AVM Treatment after Unplanned Interruption- Technical Note

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Abstract

Background and Importance—Gamma Knife radiosurgery is an established technique for non-urgent treatment of various intracranial pathologies. Intra-procedural dislodgement of the stereotactic frame is an uncommon occurrence that could lead to abortion of ongoing treatment and necessitate more invasive treatment strategies.

Clinical Presentation—In this case report we describe a novel method for resumption of Gamma Knife treatment after an unplanned intra-procedural interruption. The case example involves a radiosurgical treatment of a Spetzler-Martin Grade I arteriovenous malformation.

Conclusion—Our technique involves integration of scans and coordinate systems from two imaging sessions using the composite isodose line to resolve translational differences, thereby limiting delivery of remaining shots to the untreated region of the lesion. MRI follow-up at 13 months showed a reduction in the nidus size with no evidence of any radiation injury to the surrounding brain parenchyma. We believe this technique will allow care teams to effectively salvage interrupted gamma knife procedures and reduce progression to more invasive treatment options.

Keywords

AVM; Radiosurgery; Gamma Knife; Frame dislodgement

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Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Written consent was obtained from the patient for publication of their treatment course.

Background and Importance

Cerebral arteriovenous malformations (AVMs) carry considerable risk of hemorrhage, with natural history studies documenting annual hemorrhage rates of 1–4% per year.[1,3,5,6] Gamma Knife radiosurgery offers a cure rate of 70–90% depending on AVM size and configuration, and is reserved for non-urgent cases, as the median time to obliteration is 20 months.[4,8,7]

While numerous studies have documented the acute and chronic issues that can occur after Gamma Knife radiosurgery[2–4,8,9], there is limited literature on the nature and frequency of intraprocedural dislodgement of the stereotactic frame. To date, only one published report describes loosening or dislodgement of the stereotactic frame during Gamma Knife radiosurgery, but a method for resumption of the radiosurgical treatment was not provided. [9]

We encountered an intra-procedural interruption during Gamma Knife radiosurgery of a patient with a Spetzler-Martin Grade I AVM after the patient's abrupt, strong movement led to dislodgement of the stereotactic frame. Through this illustrative case, we describe a novel technique to resume Gamma Knife radiosurgery treatment after an unplanned interruption due to movement of the stereotactic frame.

Clinical Presentation

Institutional IRB approval was deemed not required by the Washington University Human Research Protection Office and was therefore not sought. Patient consent to publish the clinical case, however, was obtained.

A 68-year-old heavyset male was diagnosed with an asymptomatic 1.5 cm Spetzler-Martin Grade I AVM in the superior aspect of the right cerebellum, with arterial supply predominantly from the right posterior inferior cerebellar artery and the right superior cerebellar artery (Fig. 1). On the day of treatment, the patient underwent CT and MR imaging following application of the Leksell stereotactic head frame (Elekta, Stockholm, Sweden), and a treatment plan was generated. As per institutional protocol, digital subtraction angiography for dose planning is only performed when demarcation of the AVM nidus is indistinct on CT and MR imaging. In the present case, the AVM nidus was clearly delineated on axial imaging and catheter angiography was not performed. The treatment plan included 15 mixed shots to shape the 50% isodose line to encompass the AVM nidus with a target volume of 4.16 cm³. Thirty minutes into the treatment, and during delivery of the sixth shot, the patient felt claustrophobic, and moved abruptly in the machine which led to dislodgement of the stereotactic head frame. The treatment was immediately halted and the patient was discharged home with a plan to return the next day to complete treatment.

A critical issue with the unplanned, delayed, next day treatment was the inherent inability of the planning software to consolidate the first and second day MR and CT images so that the remaining shots could be administered only to the untreated portion of the nidus. The positioning of the stereotactic head frame could be different between the two imaging sessions, and the current version of the planning software cannot consolidate the two

different coordinate systems to match the treatment plans. As such, re-planning based on subsequent imaging would not be able to accurately delineate the portion of the nidus already treated before interruption of the initial treatment. During placement of the stereotactic frame on the second day, care was taken to avoid differences frame position angulation from those of the previous day. This is critical for salvage as only translational differences can be corrected through this procedure.

In order to import the original treatment plan into the new scans obtained on the second day, the relative shift between the coordinate systems would have to be resolved so that the exact position of the original fifteen shots could be transposed to the second day scans. The treatment plan and imaging from the first day were imported as a “pre-plan” where only the composite 50% isodose line around the nidus was visible. The coordinates for all fifteen shots placed on the first day plan were entered again into the “pre-plan”. However, because the pre-plan was generated without a coordinate system, the 50% isodose lines formed by the placed shots were shifted away with respect to a default origin.

Imaging obtained on the second day with the stereotactic frame affixed to the skull was then imported into the planning software and co-registered with the “pre-plan”. In order to relocate the placed shots to the AVM nidus, all of the shots were selected and manually moved in a stepwise manner until the 50% isodose line created by the sum of all fifteen shots matched the composite isodose line that was imported as part of the “pre-plan” (Fig. 2). Both the first and second day partial treatment plans were then sent to an independent treatment planning system, Eclipse™ (Varian Medical Systems, Palo Alto, California), to compare the two sets of scans and ensure that the composite isodose line around the nidus was comparable between the two sets.

In a strict, reverse order of the originally aborted treatment, all completed shots previously delivered were deleted from the new treatment plan. XYZ coordinates and sector aperture patterns were used to verify each shot before removal. It is important to verify that the treatment times are the same as those in the originally intended treatment protocol. Shots that were not delivered prior to interruption were then administered to the patient without event.

The patient underwent follow-up MR imaging and MR angiography at 13 months post-treatment. The area of enhancement corresponding to the AVM had decreased in size, measuring 1.4×1.8 cm in cross-section compared to the initial size of 1.9×2.3 cm. MR angiography showed no evidence of rapid arterial flow in the right cerebellar hemisphere indicating no residual flow within the AVM nidus (Fig. 3). In combination, these findings strongly suggest the AVM was accurately and safely targeted by our adapted approach following interrupted radiosurgical treatment.

We recognize, however, these follow-up images do not provide definitive proof that our approach delivered radiation to the identical target area that was initially planned.

Conclusion

To our knowledge, this is the first publication that describes a technique to complete Gamma Knife radiosurgery following an interruption in the middle of shot delivery caused by dislodgement of the stereotactic frame. The only previous published data on intra-procedural complications during Gamma Knife radiosurgery is a Canadian report on Gamma Knife complications resulting from frame instability during treatment. In that study, loosening of the stereotactic frame occurred in 6 of 973 (0.6%) patients and treatment was aborted in 3 of the 6 cases.[9] However, their report did not provide a description of the exact nature of the frame loosening and/or dislodgement, or the method in which the Gamma Knife treatment was resumed in the three patients who completed treatment.

While it is possible that future versions of the Leksell GammaPlan® software may allow resumption and completion of interrupted treatment, limitations in the existing Gamma Knife planning software prevent integration of scans from two different imaging sessions due to the differences from the inherently different placements of the stereotactic frame between the two days. In this report, we describe a method to manually solve this issue using the composite isodose line as a guide to resolve the translational differences between the two coordinate systems to ensure that repeat radiosurgery only targeted portions of the nidus that were not irradiated during the initial interrupted session. Another potential solution to reconciling the delivered shots during the interrupted session with the next-day completion of therapy would be to use the target volume as the point of reference for the salvage treatment planning. With the assumption that the target volume would not have changed over a course of a single day, the entire volume would be targeted with an identical treatment plan, and the shots that were previously delivered would be removed. We acknowledge that the manual placement of shots to match the isodose lines from the initial plan is subjective and exposed to human error. However, we believe that the coupling of manual placement and utilization of the Eclipse™ software to verify the isodose lines mitigates the probability of mismatched treatment volumes.

Following treatment interruption, the radiation treatment plan was improvised to allow completion of the AVM treatment over two successive days. Prior to treatment interruption, 20 Gy was delivered to an area corresponding to the left portion of the AVM target volume. A new radiation plan was generated to deliver 20 Gy to the remaining target volume the following day. A composite treatment plan (the interrupted treatment plan combined with the subsequent plan delivered the following day) was generated and compared with the original treatment plan, which showed only nominal differences. Due to the very short interval between the radiosurgical treatments in our case (one day), no compensation in radiation dose was required.

While the relative incidence of intraprocedural complications during Gamma Knife radiosurgery is rare, their occurrence can preclude timely resumption of Gamma Knife treatment and necessitates alternate, more invasive treatment strategies. Although this technical report is related to the resumption of AVM treatment, our technique for completion of treatment can be utilized in any number of Gamma Knife radiosurgical procedures, thereby salvaging the effectiveness of this non-invasive treatment modality.

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References

1. Halim AX, Johnston SC, Singh V, McCulloch CE, Bennett JP, Achrol AS, Sidney S, Young WL. Longitudinal risk of intracranial hemorrhage in patients with arteriovenous malformation of the brain within a defined population. *Stroke*. 2004; 35:1697–1702. DOI: 10.1161/01.str.0000130988.44824.29 [PubMed: 15166396]
2. Kim EJ, Vermeulen S, Li FJ, Newell DW. A review of cerebral arteriovenous malformations and treatment with stereotactic radiosurgery. *Translational Cancer Research*. 2014; 3:399–410.
3. Mohr JP, Parides MK, Stapf C, Moquete E, Moy CS, Overbey JR, Salman RA-S, Vicaut E, Young WL, Houdart E, Cordonnier C, Stefani MA, Hartmann A, von Kummer R, Biondi A, Berkefeld J, Klijn CJM, Harkness K, Libman R, Barreau X, Moskowitz AJ. Medical management with or without interventional therapy for unruptured brain arteriovenous malformations (ARUBA): a multicentre, non-blinded, randomised trial. *The Lancet*. 2014; 383:614–621. DOI: 10.1016/S0140-6736(13)62302-8
4. Monteith SJ, Yen CP, Sheehan JP. Gamma knife surgery for pediatric arteriovenous malformations: a review. *Clinical neurosurgery*. 2011; 58:126–132. [PubMed: 21916137]
5. Ondra SL, Troupp H, George ED, Schwab K. The natural history of symptomatic arteriovenous malformations of the brain: a 24-year follow-up assessment. *Journal of neurosurgery*. 1990; 73:387–391. DOI: 10.3171/jns.1990.73.3.0387 [PubMed: 2384776]
6. Stapf C, Mast H, Sciacca RR, Choi JH, Khaw AV, Connolly ES, Pile-Spellman J, Mohr JP. Predictors of hemorrhage in patients with untreated brain arteriovenous malformation. *Neurology*. 2006; 66:1350–1355. DOI: 10.1212/01.wnl.0000210524.68507.87 [PubMed: 16682666]
7. Starke RM, Komotar RJ, Connolly ES. A randomized trial of unruptured brain arteriovenous malformations. *Neurosurgery*. 2013; 73:N13–15. DOI: 10.1227/01.neu.0000435114.33768.e3
8. Starke RM, Komotar RJ, Hwang BY, Fischer LE, Otten ML, Merkow MB, Garrett MC, Isaacson SR, Connolly ES Jr. A comprehensive review of radiosurgery for cerebral arteriovenous malformations: outcomes, predictive factors, and grading scales. *Stereotactic and functional neurosurgery*. 2008; 86:191–199. DOI: 10.1159/000126945 [PubMed: 18421250]
9. Vachhrajani S, Fawaz C, Mathieu D, Menard C, Cusimano MD, Gentili F, Hodaie M, Kenny B, Kulkarni AV, Laperriere N, Schwartz M, Tsao M, Bernstein M. Complications of Gamma Knife surgery: an early report from 2 Canadian centers. *Journal of neurosurgery*. 2008; 109(Suppl):2–7. DOI: 10.3171/jns/2008/109/12/s2 [PubMed: 19123881]

Figure 1.

Axial, coronal, and sagittal MRI (A, B, and C respectively) demonstrating the contoured AVM nidus at the right suboccipital surface

Figure 2.
Coronal and sagittal MRI scan slices showing complete coverage of the contoured nidus from shots placed on the first day (A and C) and second day (B and D).

Figure 3. Coronal and sagittal MRI scan slices prior to treatment (A and C) and 13-months post-treatment (B and D) demonstrating reduction in nidus volume.