Adenosine-induced cardiac standstill for endovascular treatment of pediatric vein of Galen malformations

Nam K. Yoon, MD, Jonathan P. Scoville, MD, and Philipp Taussky, MD

Department of Neurosurgery, Clinical Neurosciences Center, University of Utah Health Care, Salt Lake City, Utah

Vein of Galen malformations are congenital high-flow vascular malformations that often present with heart failure, hydrocephalus, developmental delay, and intracranial hemorrhage. Because open surgical treatment is associated with high morbidity and mortality, endovascular embolization is increasingly becoming the preferred method of intervention. However, embolization of these lesions can be difficult because of their high-flow nature. The use of adenosine-induced cardiac standstill for treatment of vein of Galen malformations has not been previously described in neonates. The authors describe 3 treatments in 2 patients that demonstrate that the use of adenosine is well tolerated and allows safe transarterial embolization of high-flow vein of Galen malformations in the pediatric population.

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demonstrated that the use of adenosine for treatment of arrhythmias or in endovascular procedures in the pediatric population is both safe and effective.\(^2,7,13\) Although the technique of adenosine-induced cardiac standstill to aid in the endovascular treatment of vein of Galen malformations has been previously reported in adults,\(^16\) it has not been previously described in infants. We present here 3 instances of the use of adenosine to induce cardiac standstill in 2 infants who underwent endovascular embolization of their high-flow arteriovenous shunts.

**Case Presentations**

**Case 1**

This male infant was diagnosed with a “midline brain cyst” on prenatal ultrasonography. Despite this finding, his birth was unremarkable at 38 weeks of gestation. He was normocephalic, was neurologically intact for age, and had no signs of high-output cardiac failure or end-organ dysfunction. MRI and MR angiography (MRA) demonstrated a 10-mm left anterior frontal lobe venous aneurysm supplied by an enlarged frontopolar branch of the left anterior cerebral artery (ACA), with 2 large varices within the drainage pathway (Fig. 1A). The patient developed progressive enlargement of the venous aneurysm, enlargement of the lateral ventricles, and frank macrocephaly. At 6 months of age, he had successful coil embolization of the main arterial feeder arising from ACA. This significantly slowed the filling of the vein of Galen malformation, and follow-up imaging showed reduction in size of the malformation (Fig. 1B).

At 12 months of age, the patient underwent further endovascular treatment. The fistulous point arising from the ACA was accessed with a Marathon (Medtronic) microcatheter. Onyx 34 was slowly injected to embolize the arterial feeder, but because of the high-flow nature of the vascular malformation, an Onyx plug did not form. Several boluses of adenosine were administered in progressively larger doses to assess sensitivity and tolerability. Finally, a 5-mg bolus of adenosine (0.5 mg/kg) was sufficient to induce a few seconds of cardiac standstill. This allowed a small Onyx plug to develop, and after return to baseline cardiac function, a second 5-mg bolus was administered, allowing a larger Onyx plug to develop. This was then pushed anterograde into the fistulous point and achieved successful occlusion of the feeding vessel (Fig. 1C). Later, at 30 months of age, the patient underwent endovascular treatment of the fistulous point arising from the middle cerebral artery. Again, because of the high-flow nature of this lesion, initial efforts at creating an Onyx plug failed and again progressively larger doses ranging from 1 mg to a maximum of 0.5 mg/kg of adenosine were administered to achieve brief cardiac standstill and allow formation of an Onyx plug (Fig. 1D). The patient tolerated both procedures well, without neurological or cardiac adverse events. His progressive hydrocephalus and macrocephaly stabilized (Fig. 2), and he continued to develop normally until his last follow-up visit at 3 years of age.

**Case 2**

This male infant was found at birth to have pulmonary hypertension and early congestive heart failure. On further workup, a high-flow fistulous connection with an arterial feeder arising from the right posterior cerebral artery (PCA) and draining into a dilated persistent vein of Markowski was found on MRI (Fig. 3A and B). Initially,
the child appeared neurologically intact for age and was temporized with sildenafil for his pulmonary hypertension; however, at 12 weeks of age, his cardiorespiratory function began to deteriorate, and neurosurgical intervention was more urgently needed. During angiography, it was clear that coils would not stay in place because of the high-flow nature of the fistula (Fig. 3C). An initial attempt at Onyx embolization failed, and Onyx was embolized downstream into the distal venous system. Residual flow was still detected, so Onyx 34 was used to completely occlude the fistulous connection (Fig. 3D). Despite his cardiorespiratory decompensation, the patient tolerated the adenosine boluses and the procedure well, without neurological or cardiac complications. His respiratory and heart function improved immediately, and at his most recent follow-up visit, at 3 years of age, he was developing normally without any neurological or cardiorespiratory issues. MRI/MRA demonstrated stable appearance of the vasculature without evidence of hydrocephalus (Fig. 4).

Discussion

When left untreated, congenital vein of Galen malformations that present in the neonatal period are associated with high morbidity and mortality, particularly when patients present early with high-output cardiac failure. Often, surgery cannot be delayed until these neonates are large enough to tolerate open surgery. Additionally, open surgery to obliterate these lesions can be associated with mortality rates up to 91% in newborns. Consequently, endovascular approaches, despite being associated with poorer outcomes when performed in neonates, have become the first-line method of definitive treatment. Recent improvements in microcatheters and wires and development of liquid embolic materials have improved outcomes significantly.

In our experience with treating vein of Galen malformations, the main limitation relates to the high-flow arteriovenous shunting associated with these lesions. Endovascular embolization can be difficult because both Onyx and detachable coils have poor stability within the high-flow fistulous target. These difficulties have been reported in other studies, and one group described the use of adenosine for the treatment of the high-flow fistulous point in an adult patient with vein of Galen malformation. Another group reported the use of rapid ventricular pacing to reduce mean arterial pressure and blood flow to treat a posterior choroidal fistulous connection in an infant with a vein of Galen malformation. In both studies, decreasing the flow was necessary for the safe embolization of the fistulous connection.

Here, we present 3 instances in 2 infants where adenosine-induced cardiac standstill allowed the controlled and safe embolization of the high-flow fistulous connection associated with vein of Galen malformations. The administration of adenosine was well tolerated, with spontaneous return of normal sinus rhythm and blood pressure, and without adverse cardiac side effects. This was demonstrated even in our second patient, who developed cardiopulmonary decompensation prior to endovascular treatment. Embolization of his fistula resulted in almost immediate resolution of his cardiopulmonary insufficiency. This is consistent with previous reports showing that adenosine-
induced cardiac standstill is well tolerated in neonates and young infants.\textsuperscript{7,13}

**Conclusions**

Vein of Galen malformations are associated with high rates of morbidity and mortality, particularly when they present in the neonatal period. Although medical management can help alleviate symptoms, obliteration of the high-flow fistula may be urgently required when medical management fails and cardiopulmonary decompensation develops. Here, we present an endovascular approach using adenosine-induced cardiac standstill to allow the safe and controlled embolization of the high-flow arteriovenous shunts associated with these aggressive lesions in infants.

**References**


**Disclosures**

Dr. Taussky reports a consultant relationship with Medtronic.

**Author Contributions**

Conception and design: all authors. Acquisition of data: all authors. Analysis and interpretation of data: all authors. Drafting the article: Yoon, Scoville. Critically revising the article: Taussky. Reviewed submitted version of manuscript: all authors. Study supervision: Taussky.

**Correspondence**

Philipp Taussky: University of Utah Health Care, Salt Lake City, UT. neuropub@hsc.utah.edu.