Use of the Valsalva Maneuver in Addition to Controlled Hypotension During Endovascular AVM Embolization: A Novel Approach to Reducing Distal Particle Embolization?

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Author’s contribution

Dr. Harris designed the study, wrote the protocol, performed the literature searches, managed the analysis of the study, and wrote all drafts of the manuscript.

ABSTRACT

Study Objective: To report the use of a sustained Valsalva maneuver during deliberate hypotension in order to reduce the incidence of distal particle embolization during the neuroangiographic embolization of intracranial arteriovenous malformations (AVMs).

Design: Retrospective case series.

Patients: 54 cases were studied involving 46 unique patients (20 male, 26 female) seen between January 1, 2007 and December 31, 2008. All patients were ASA class II-III and were undergoing neuroangiographically-assisted embolization for intracranial AVMs.

Intervention: Immediately prior to the injection of the embolic substance, each patient received a dose of nitroglycerin to lower their systolic blood pressure from baseline (112-146 mm Hg) to a target of 55 mm Hg. Next, mechanical ventilation was suspended and manual pressure was applied to the ventilation bag of the anesthesia circuit to maintain a constant airway pressure of 20 cm H2O. This simulated Valsalva maneuver was maintained for 15 seconds after the injection of the embolic material, at which point mechanical ventilation was resumed.

Main Results: All patients tolerated the deliberate hypotension/Valsalva protocol well. 2 patients experienced a rupture of the AVM during the procedure.
Conclusions: The distal embolization of the embolic material during intracranial AVM embolization is a potentially fatal complication of this procedure. Although our results represent a small case series, they suggest that the use of deliberate arterial hypotension in addition to a simulated Valsalva maneuver may enhance the safety and efficacy of intracranial AVM embolization. Further study, with rigorous control standards and monitoring, is warranted.

Keywords: Arteriovenous malformation; intraoperative hypotension; Valsalva maneuver; particle embolization.

1. INTRODUCTION

Over the past two decades, it has become increasingly common for patients with intracranial arteriovenous malformations (AVMs) to receive at least their initial therapy in the neuroangiography suite (Van Rool et al., 2007). Lesions that were at one time surgically excised can now be treated via transcatheter embolization and even AVMs that will ultimately require surgical management can be significantly devascularized beforehand using particle embolization, thereby minimizing surgical blood loss and morbidity (Spetzler et al., 1987; Pasqualin et al., 1991). Non-invasive radiosurgery (e.g. Gamma Knife®) another option for non-surgical AVM management, may also be preceded by transcatheter embolization to shrink the AVM prior to definitive radiosurgery (Mathis et al., 1995). The endovascular approach, however, is not without its own unique set of complications. Chief among them is the risk of venous deposition or distal embolization of the embolic substance used by the radiologist or neurosurgeon (Barr and Lemley, 1997; Dalyai et al., 2011). It is supposed that risks of venous deposition or distal embolization should be reduced by an extremely low cerebral blood flow (CBF). With this in mind, we used a combination of deliberate hypotension and a Valsalva maneuver when the embolic solution was injected.

2. MATERIALS AND METHODS

This case series describes 54 cases performed at our hospital between January 1, 2006 and December 31, 2007. The protocol for this study was submitted to our Institutional Review Board as a retrospective case review, and permission was given to precede pending informed consent from each patient to review their medical charts, which was received. 20 men and 26 women were all treated for intracranial AVMs in the neuroangiography suite. 8 patients (2 men, 6 women) returned for a second series of embolizations within that time period. All lesions were treated by the instillation of Onyx® liquid embolic system (Micro Therapeutics Inc., Irvine, CA) via a femorally-introduced flow directed micro catheter. The age range of patients was 22 – 84 years old, with a mean age of 44.2 years. No patients had a history of chronic hypertension (either present at the time of the procedure or currently treated with medication,) carotid disease, angina, myocardial infarction, congestive heart failure, chronic pulmonary disease, or an ASA classification greater than III. All patients were monitored with a 5-lead electrocardiogram, a non-invasive blood pressure cuff set to measure at 5-minute intervals, pulse oximetry, a nasopharyngeal temperature probe, and end-tidal CO₂ monitoring. Electroencephalographic monitoring was not used due to the radiologists’ requests to keep the patients’ heads free of all radio-opaque objects in all planes. Midazolam was given intravenously prior to induction if warranted to reduce anxiety.
Induction proceeded with propofol (2 mg/kg) and rocuronium (.7 mg/kg) and repeat doses of 10 mg were given to maintain no more than 1 twitch via a peripheral nerve stimulator. Fentanyl 3 mcg/kg was given prior to tracheal intubation. Patients’ lungs were ventilated by a controlled-volume ventilation mode with a gas mixture of 30% O_2 / 70% N_2O and 1.5 MAC of sevoflurane. The inhaled agent was adjusted to keep the mean blood pressure within 10% of pre-induction values (determined from the patient’s pre-operative physical examination). If hypotension remained at 1 MAC of sevoflurane, we would begin a phenylephrine infusion, starting at 25 mcg/min and titrating upward until the blood pressure target was achieved. Patients were mechanically ventilated with tidal volumes ranging from 8-10 cc/kg. Respiratory rate was adjusted to keep ETCO_2 between 32-35 mm Hg. Tachycardia (which we defined as a heart rate greater than 20% above pre-induction levels in the absence of hypotension) was treated with 50 mcg fentanyl boluses; persistent tachycardia after the narcotics was treated with 5 mg boluses of esmolol. Arterial access was obtained in the radial artery (42 patients in the right radial, 12 patients in the left) for every patient after induction. At the radiologist’s request, each patient received heparin boluses (3,000 U initially, followed by 1,000 U boluses to maintain an activated coagulation time [ACT] 2 – 3 times baseline). Lactated Ringer’s solution was administered intravenously at a rate of 125 ml/hr.

A diagnostic neuroangiogram was initially performed to elucidate the anatomy of each AVM. The number and caliber of arterioles feeding the AVM (Fig. 1) as well as the venous drainage pattern (Fig. 2) were assessed.

![Fig. 1. A large AVM (red arrows) supplied by several feeding arterioles (green arrows)](image)

ICA = internal carotid artery. MCA = middle cerebral artery
When the micro catheter was optimally positioned and the radiologist was ready to inject the Onyx®, the patient was given an intravenous bolus dose of nitroglycerin 1 mcg/kg, with the intention of lowering the systolic blood pressure to 55 mm Hg. If this goal was not achieved within 30 seconds of the initial bolus, repeat doses of 0.25 mcg/kg were given every 15 seconds until the target systolic blood pressure was reached. NTG was effective in all cases to achieve the target blood pressure. Once the blood pressure was at the desired range,
mechanical ventilation was halted and manual pressure was applied to the ventilation bag of the anesthesia circuit to maintain a constant airway pressure of 20 cm H$_2$O. At this time, the radiologist injected the Onyx® solution, which was typically given over 3–5 seconds. Afterward, the airway pressure was maintained at 20 cm H$_2$O for 15 seconds while systolic blood pressure was kept in the target range by further instillation of nitroglycerin (if necessary). After 15 seconds, the Valsalva was released, mechanical ventilation was resumed, and the blood pressure was allowed to return to its previous normal range. Angiography performed at this time typically showed the Onyx® solution hardened within the target vessel (Fig. 3). If the patient required further embolizations, we allowed at least 15 minutes elapsing before the procedure was repeated.

3. RESULTS

All patients tolerated the anesthetic course well, with no apparent complications related to the hypotension/Valsalva protocol. 47 patients were given 1-2 mg of midazolam prior to induction. Due to the lack of surgical stimulation after groin incision and arterial cannulation, narcotics were necessary in only three patients; only a single patient required fentanyl and a single dose of esmolol. 52 of the cases were extubated at the end of the procedure with no neurological deficit apparent after examination by the radiologist. 2 patients experienced a rupture of the AVM during the procedure. Both cases were treated with protamine 0.5 mg/kg to reverse the anticoagulation and intravenous nicardipine to lower the blood pressure. Both patients were taken to the computerized tomography (CT) scanner to evaluate the extent of the intracranial bleeding. One patient was found to have limited bleeding and was managed conservatively. The second patient was found to have a more extensive bleed and was transferred to the surgical suite for ventriculostomy and further surgical management. In both cases, the rupture happened after the radiologist had successfully embolized one site and was repositioning the micro catheter to attempt a second embolization at a different location.

4. DISCUSSION

While neuroendovascular embolization has proven to be a safe and efficacious mode of therapy, it does come with its own set of proprietary complications (Asouhidou et al., 2007). Infection or bleeding at the femoral puncture site (Geyik et al., 2007), occult retroperitoneal bleeding (Tomlinson et al., 1999), arterial occlusion requiring thrombectomy or thrombolysis (Citron et al., 2003; Quereshi et al., 2000) and rupture of the intracranial lesion in a fully anticoagulated patient (Biondi et al., 2006) must all be guarded against by the radiologist and the anesthesiologist. However, one of the most ominous complications unique to this procedure is the distal embolization of the embolic material. The hardened glue can cause localized venous obstruction resulting in occlusion of the draining veins, increased pressure within the AVM and possible nidus rupture (Massoud et al., 2000). Furthermore, the embolic material can circulate distally to the pulmonary vascular bed, or (if the patient has a patent foramen ovale or a ventricular septal defect) embolize into the arterial circulation.

In an effort to reduce the incidence of distal embolic phenomena, physicians have employed different techniques to reduce cerebral blood flow (CBF) and therefore slow the flow of the glue through the AVM. Clinicians have gone as far as using adenosine to produce a transient high-degree atrioventricular block, thereby allowing the radiologist to inject the embolic material under a flow-arrest or extremely low flow environment (Pile-Spellman et al., 1999; Hashimoto et al., 2000). More commonly, anesthesiologists use agents such as
nitroglycerin (Lai et al., 2000), sodium nitroprusside (Moss, 1995), esmolol (Ornstein et al., 1991), or labetolol (Schaeder et al., 1991) to reduce the arterial blood pressure without blocking intracardiac conduction. This method has been shown to increase transit time through the AVM in computer models of intracranial vasculature (Gao et al., 1997). Some physicians choose to avoid primary arterial vasodilators out of a concern that their use will result in an increase CBF with an accompanying cerebral steal phenomena (Blackburn et al., 1997). Most neuroradiologists prefer the patient to remain normotensive or even slightly hypertensive at all times beside the actual embolization. Due to the flow directed nature of the micro catheter, it is technically challenging to correctly place it in a hypotensive patient; a slightly hypertensive patient with brisk CBF will allow the micro catheter to more easily be directed into its target vessel (Osborn, 2003). Hypertension also enhances CBF through collateral anterior communicating arteries or leptomeningeal circulation in the event of intentional or unplanned vasculature occlusion (Young and Cole, 1993). Concerns that an augmentation of systemic blood pressure will result in rupture of an AVM have been clinically disproven (Szabo et al., 1989). While the blood pressure can usually be supported by limiting the amount of volatile agent, pharmacologic therapy may be needed to maintain adequate CBF while still ensuring an adequate depth of anesthesia. As discussed earlier, we have had good results using a phenylephrine infusion, starting at 25 mcg/min and titrating upward until the blood pressure target is achieved.

Manipulation of minute volume to lower PaCO<sub>2</sub> can be used as a measure of reducing CBF and thereby delaying outflow from the AVM. However, when hyperventilation is used simultaneously with controlled hypotension, cerebral ischemia will occur at a higher blood pressure than it would if the PaCO<sub>2</sub> was held in the normal range (Rosas, 2007). Given a choice between one of the two methods, we find that altering the blood pressure in either direction can be done more precisely and more quickly than manipulating PaCO<sub>2</sub>.

It is interesting to note that hypercapnia has been described as a useful technique in the treatment of extra cranial facial AVMs. In these cases, the embolic material is actually injected into the vein via a catheter introduced in the femoral vein. The rise in CBF secondary to the higher PaCO<sub>2</sub> increases intracranial venous drainage to a greater degree than extra cranial drainage, thereby creating a gradient that minimizes the chance of intracerebral migration of the embolic material (Young and Pile-Spellman, 1994).

The Valsalva maneuver is physiologically divided into four phases: Phase I am marked by the onset of straining and the early rise of intrathoracic pressure. Blood pressure begins to rise, but there is typically no change in heart rate. Phase II begins with the onset of decreased venous return and the resultant decrease in stroke volume and blood pressure; the heart rate increases via autonomic stimulation. Phase III is marked by the release of straining with a return of normal intrathoracic pressure and pulmonary blood flow. Phase IV is characterized by an overshoot of blood pressure above normal and a return of the heart rate to its normal range. Transcranial Doppler (TCD) studies reveal that intracerebral blood flow velocity (ICBFV) varies directly (but to a greater degree) than systemic blood pressure (SBP) (Pott et al., 2003; Pott et al., 2000). During Phase II, ICBFV decreased by 35% (vs. a SBP decrease of 10.2%); during Phase IV ICBFV increased 56.5% (vs. a SBP elevation of 29.8%) (Tiecks et al., 1995). These changes in ICBFV are due to both the mechanical effects of increased intrathoracic pressure (most notably a significant drop in critical closing pressure at the start of Phase IV) (Dawson et al., 1999) as well as autonomic neural activity (Korner et al., 1976). Ganglionic blockade with trimethaphan resulted in a significantly larger drop of ICBFV during Phase II (60% vs. 33% in controls) and a more robust rebound during Phase IV (55% vs. 46% in controls) (Zhang et al., 2004), suggesting that the role of the
The autonomic system is to reign in the exaggerated mechanical response. These autonomic pathways have been elegantly mapped with the assistance of functional MRI: the initial autonomic impulses arise in the rostral brain areas, with later contributions from the cerebellar nuclei, basal ganglia and the lateral prefrontal cortex.

The Valsalva maneuver is used as an adjunct for a range of diagnostic studies in the radiology department. Patients with significant carotid artery stenosis display altered flow dynamics in the distribution of the middle cerebral artery ipsilateral to the carotid disease during a forced Valsalva. Most notably, there is an uncoupling between the parallel courses of ICBFV and SBP, with blunted ICBFV responses in both Phases II and IV (Tiecks et al., 1996). The Valsalva maneuver significantly increases the sensitivity of TCD and may obviate the need for more invasive neuroangiographic studies. The Valsalva maneuver has also been used extensively during nuclear medicine studies to assess asymmetric cerebral blood flow due to AVMs (Friedman et al., 1974) or intracardiac shunts (Hayashida et al., 2001). Our use of the Valsalva maneuver for a therapeutic reason has not been cited in the neuroradiology literature, although it is widely cited as a means of treating superior supraventricular tachycardias (Delacretaz, 2006; Smith et al., 2009).

None of our patients required central venous pressure monitoring. Fluid shifts, bleeding, and air embolus are rarely seen with intravascular management of AVMs, so central venous catheterization is not typically performed unless clinically warranted by an underlying medical condition (Ahmed, 2007). Therefore, our study was limited by the fact that we didn’t have a measurement of how much the CVP was raised with the addition of 20 cm H2O of PEEP. The addition of 10 cm H2O of PEEP in patients with normal pulmonary compliance is felt to raise CVP by less than 3 mm Hg, yet the non-linear relationship between the two parameters suggests that higher levels of PEEP may augment the slope of the CVP curve more steeply (Magder, 2006). Furthermore, we do not have empirical evidence that the increase in CVP slowed transit time through the AVM.

5. CONCLUSION

The results of this case study suggest that further clinical study of the flow dynamics in intracranial AVMs during hemodynamic manipulation is warranted. The next logical step would be to complete a prospective controlled study with a larger number of patients, aggressive monitoring (including CVP) and rigorous testing standards. Based solely upon this review, it cannot be assumed that risks of embolization of intracranial AVMs are minimized using these techniques. Therefore, a ‘general recommendation’ of this present method cannot be done due to the aforementioned limitations of this study. Anesthesiologists must provide adequate monitoring and sufficient opportune therapies to facilitate the procedure and maximize the likelihood of success. Among them, the combination of a Valsalva maneuver and deliberate hypotension seems a possible approach to induce an extremely low CBF through the AVM and thus, to reduce the risk of venous deposition or distal embolization at the site of the glue injection.
CONSENT

The author declares that written informed consent was obtained from the patient (or other approved parties) for publication of this case report and accompanying images.

ETHICAL APPROVAL

The author hereby declares that all experiments have been examined and approved by the appropriate ethics committee and have therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

COMPETING INTERESTS

The author has declared that no competing interests exist.

REFERENCES


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