Air gun orbitocranial penetrating injury: emergency endovascular treatment and surgical bypass following pellet migration to middle cerebral artery: case report

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The authors describe a 14-year-old boy presenting with an orbitocranial penetrating injury (OPI) from a metallic air gun pellet to the left eye who developed hemiparesis and speech difficulty due to migration of the pellet to the left middle cerebral artery. They highlight the potential complications associated with both OPIs and intravascular foreign body migration and occlusion by describing the patient's presentation, results of imaging evaluation, and the combined endovascular treatment and extracranial-intracranial bypass, which resulted in rapid restoration of blood flow and full neurological recovery with intact vision. Based on this case and a review of the literature on intracranial foreign body migration with resultant vascular occlusion, the authors recommend that complex OPIs be treated at centers that offer both neuroendovascular and neurovascular surgical capabilities on an urgent basis to manage both the primary injury and potential secondary vascular compromise.

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KEY WORDS orbitocranial penetrating injury; pellet embolus; extracranial-intracranial bypass; stroke; trauma

Despite the diverse nature of orbitocranial penetrating injuries (OPIs), general guidelines for imaging and surgical protocols have emerged, and patterns of injury types have been recognized and described.[33,45,47] Rarely, cases of shotgun pellets migrating from the primary injury site to the intracranial arteries have been reported.[44] The successful management of these complex cases requires treatment of the primary injury as well as any potential secondary vascular compromise. We report a case of pellet migration following an OPI that was managed through a coordinated multidisciplinary effort, which included a novel attempt at endovascular treatment and successful surgical intervention.

Case Report

History and Examination

A 14-year-old boy suffered a hunting accident in which a pellet from an air gun penetrated his left orbit. On admission to a regional hospital, the patient was noted to have a penetrating injury to his upper eyelid, with a very swollen eye that precluded assessment of vision. A mild right hemiparesis was noted as well. These findings prompted air transfer to our center for more detailed assessment and treatment. During transport, the patient demonstrated fluctuating speech difficulty and worsening right hemiparesis. On arrival, he underwent CT scanning, which showed the metallic pellet in an intracranial location (Fig. 1). Emergency cerebral angiography revealed a small carotid cavernous fistula (CCF), suggesting that the pellet had entered the cavernous internal carotid artery (ICA) and migrated distally to become wedged in the mid–M_1 segment of the middle cerebral artery (MCA), completely obstructing flow (Fig. 2).

Operation

An attempt was made to remove the pellet by using

ABBREVIATIONS CCF = carotid cavernous fistula; EC-IC = extracranial-intracranial; ICA = internal carotid artery; MCA = middle cerebral artery; OPI = orbitocranial penetrating injury; STA = superficial temporal artery.
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FIG. 1. Admission axial CT scan obtained without contrast demonstrating a metallic artifact in the expected distribution of the left MCA.

an endovascular suction device (the Penumbra aspiration system; Penumbra Inc.), but a suction lock could not be achieved, and attempts to retrieve the pellet were unsuccessful in moving it; the pellet appeared to be wedged tightly in its location. The CCF was quickly treated transarterially with coil occlusion (detachable coils, Boston Scientific Co.), and the patient underwent emergency extracranial-intracranial (EC-IC) bypass using a superficial temporal artery (STA)-MCA graft (Fig. 3).

FIG. 3. Postcoiling angiogram of the CCF. Lateral unsubtracted left ICA angiogram showing interval placement of a metallic coil (*arrow*) in the posterior genu of the cavernous carotid artery, with resultant occlusion of the CCF.

Intraoperative angiography demonstrated good filling of the distal MCA vasculature, with retrograde filling of the M_1 down to the level of the pellet (Fig. 4). The ophthal-

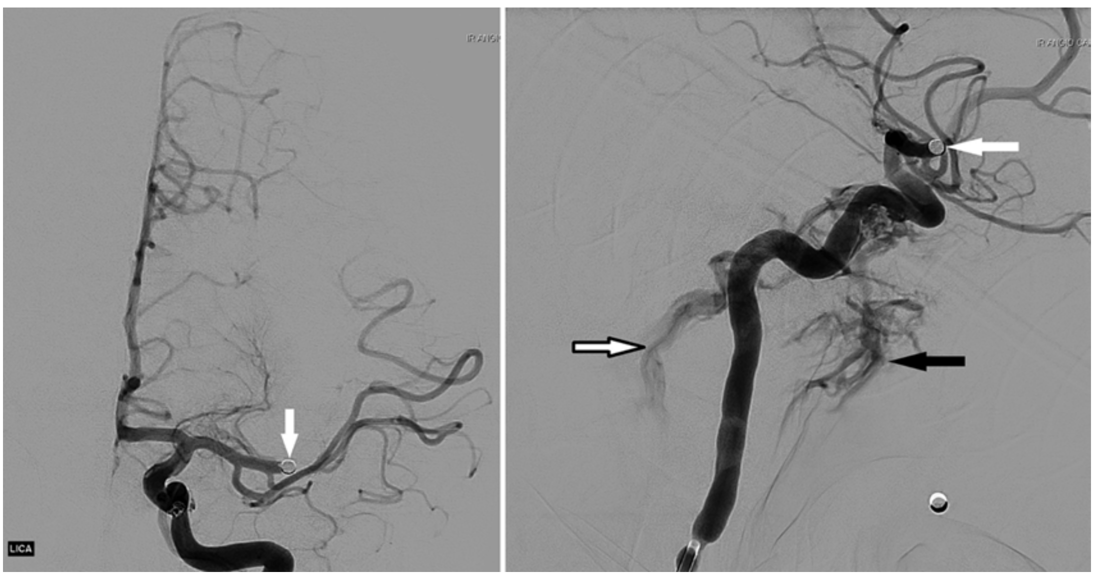

FIG. 2. Initial left ICA angiograms showing MCA flow occluded by the air gun pellet (left), and the CCF (right). **Left:** Anterior-posterior view, demonstrating abrupt cutoff in the distal M_1 segment by a round object (*arrow*) shown by a slight subtraction artifact. There are 2 anterior temporal branches arising from the mid-M_1 perfusing only a small portion of the MCA territory. **Right:** Lateral view, demonstrating a high-flow CCF in the region of the horizontal portion of the cavernous carotid artery, with venous drainage via the inferior petrosal sinus and pterygoid plexus. *Arrows* point to the pellet (*white arrow*), the inferior petrosal sinus (*outlined arrow*), and the pterygoid plexus (*black arrow*).

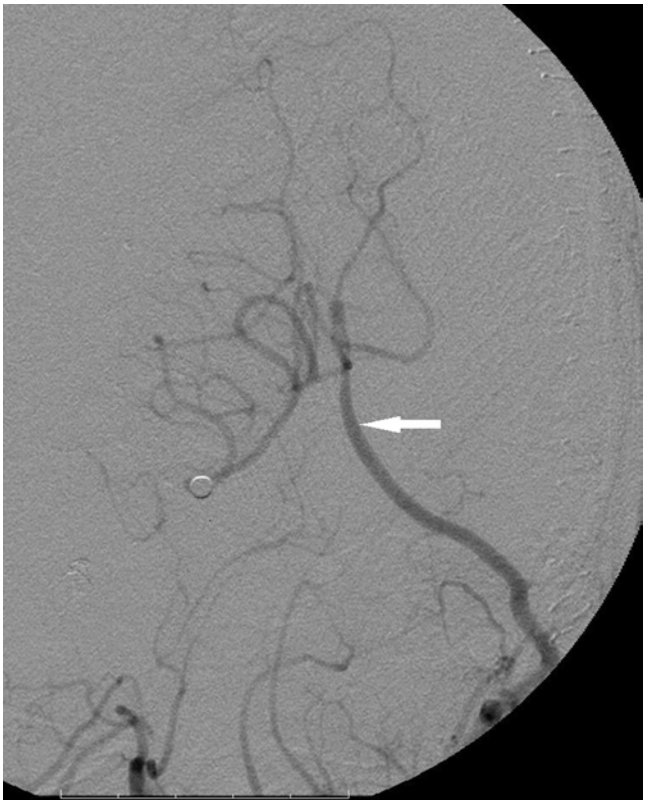

FIG. 4. Follow-up angiogram of STA-MCA bypass (*arrow*). Oblique digital subtraction angiography view of the left external carotid artery showing excellent opacification of the STA, with resultant retrograde filling of the MCA to the level of the pellet.

FIG. 5. Follow-up CT showing ischemic infarct. Axial CT scan obtained without contrast demonstrating a small area of hypodensity (*arrow*) in the dorsal aspect of the left lentiform nucleus.

mic artery was patent following treatment and there was persistent occlusion of the fistula.

Postoperative Course

Immediately after surgery, the patient's hemiparesis resolved, and his speech had normalized by the following day. At the 6-month follow-up, the EC-IC bypass remained patent and, despite evidence of a small hypodensity in the dorsal aspect of the left lentiform nucleus, the patient had no neurological symptoms, and he had intact vision (Fig. 5).

Discussion

Our case of pellet migration and occlusion of the MCA highlights a rare but interesting sequela of OPI secondary to a projectile object. The initial CCF was treated endovascularly;[27] however, endovascular techniques failed to retrieve the pellet, leaving the M_1 segment of the MCA occluded. Ultimately, rapid surgical intervention was required to restore cerebral blood flow in this case. We agree with prior reports that have emphasized the importance of a multidisciplinary team approach that incorporates input from imaging and surgical experts to allow for optimal management of damaged or tamponaded blood vessels and possible removal of the foreign pellet, if possible, to decrease infection risk.[8,35]

Although intravascular migration and occlusion of blood vessels by penetrating missile fragments most commonly affects the thorax and extremities,[53] migration to the intracranial circulation has been reported for shotgun and air gun pellets or metal fragments in 46 cases (Table 1).[44] In these reports, pellets most commonly embolized from arteries in the upper chest or neck to the intracranial circulation, because pellets in venous circulation or below the heart would most likely embolize to the limbs or other locations.[41] As shown in Table 2, intracranial pellets most often caused occlusion of the MCA (30 of 46, 65.2%),[43] but also occluded the ICA (8 of 46, 17.4%), posterior cerebral artery (4 of 46, 8.7%), or other intracranial arteries (4 of 46, 8.7%).[12] Common symptoms include hemiplegia, hemiparesis, aphasia, weakness, and visual field deficits. Migration of fragments occurs most commonly with small pellets from air guns (4 of 46, 8.7%) or shotguns (32 of 46, 69.6%); the low (< 100 m/second) to mid (< 250 m/second) impact velocities of these missiles means that they are more likely to lodge in soft tissue and lacerate blood vessels rather than cause shock waves and cavitation or exit the body.[36] Migration within intracranial circulation is restricted to pellets of a size that can be carried within the ICA, and the prevalence of arterial rather than venous migration suggests a link between high flow velocity and pellet migration.[48]

In symptomatic cases, there are a variety of treatment options to restore cerebral blood flow. Endovascular therapy using a balloon catheter was successful in 1 case of intracranial pellet embolus, although the patient had persistent neurological deficits.[38] Although endovascular suction failed in our case, it could be considered as a reasonable first-line treatment option because of its minimally invasive nature, potential to achieve rapid restoration of flow, and its relative safety. The retrieval of migrated coils and balloons during intravascular aneurysm treatment provides some precedent for endovascular pellet retrieval in this setting,[11,16] with endovascular suction, stent retrievers, and alligator retrieval devices having high rates of suc-

TABLE 1. Literature review of intracranial foreign object migrations and occlusions

Authors & Year	Age (yrs), Sex	Type of Projectile	Location of Injury	Location of Migration	Symptoms of Embolus	Treatment for Embolus	Long-Term Clinical Outcome
Lecene & Lhermitte, 1920	30, M	Metal fragment	Lt neck	Lt MCA	Agitation, paralysis, palsy	No intervention	Death
Dowzenko, 1946	29, M	Steel splinter	Neck	Rt MCA	Hemiplegia	No intervention	Hemiplegia
Barrett, 1950	32, M	Shotgun pellet	Lt neck	Branch of MCA	Aphasia, rt hemiplegia	No intervention	Long-term aphasia, rt hemiplegia
	30, M	Metal fragment	Neck	Branch of MCA	Aphasia, hemiplegia	No intervention	Death
Piazza & Gaist, 1960	22, M	Shotgun pellet	Neck	Lt MCA	Hemiparesis	Craniotomy, embolectomy	Mild hemiparesis
Van Gilder & Coxe, 1970	21, M	Shotgun pellet	Neck	Lt MCA	Hemiparesis, dysphasia	Embolectomy	Moderate hemiparesis, dysphasia
Kapp et al., 1973	39, M	Shrapnel	Chest	Rt MCA	Hemiparesis	Embolectomy	Hemiparesis
Padar, 1975	56, M	Air gun pellet	Neck	Rt ICA	None reported	No intervention	Complete recovery
Miner & Handel, 1978	13, M	Shotgun pellet	Neck	Rt ICA	None reported	No intervention	Complete recovery
Sethi & Rozdilsky, 1978	27, M	Shotgun pellet	Heart	Rt ICA	Weakness of lt eye rectus, hemiparesis	No intervention	Death
Havill & Wynne-Jones, 1979	18, M	Shotgun pellet	Rt chest	Rt MCA	Lt hemiplegia, cranial nerve palsies	No intervention	Apraxia & astereognosis, lt hemiparesis
Glass et al., 1980	24, M	Shotgun pellet	Chest	Bilat ICA	None reported	No intervention	Death
Kase et al., 1981	24, M	Shotgun pellet	Heart	Rt MCA	Edema, uncal herniation	No intervention	Death
Gipe et al., 1981	21, M	Shotgun pellet	Rt chest	MCA	Dilated & hyporeactive pupils, decorticate posturing	No intervention	Death before surgery could begin
Hungerford et al., 1981	8, M	Shotgun pellet	Lt neck, face	Lt PCA	Lt hemiparesis, hypertension, edema, apnea, bradycardia	No intervention	Death
Vascik & Tew, 1982	12, M	Shotgun pellet	Chest	Rt MCA	Lt hemiplegia	Craniotomy, embolectomy	Mild spasticity
	23, M	Shotgun pellet	Chest	Rt MCA	Nonresponsive	No intervention	Complete recovery
Alsofrom et al., 1982	17, M	Shotgun pellet	Rt hemithorax	Rt & lt MCAs	Mild neuro deficits, apathy, dysarthria	No intervention	Persistent mild aphasia
Bahnini et al., 1986	24, M	Shotgun pellet	Neck, rt hemithorax	MCA	Contralat hemiplegia	No intervention	Persistent arm paresis
Abdo et al., 1988	18, M	Shotgun pellet	Neck	Lt MCA	None reported	No intervention	Complete recovery
Dadsetan & Jinkins, 1990	17, M	Shotgun pellet	Rt eye area	MCA	Lethargy, aphasia, rt hemiparesis	Craniotomy, embolectomy	Lt side sensory motor deficit, central nerve palsy
	30, M	Shotgun pellet	Chest	Rt proximal MCA	Nonresponsive	Craniotomy, embolectomy	Lt hemiparesis, aphasia, neuro deficit
Langenbach et al., 1990	52, M	Metal fragment	Neck	MCA	Hemiparesis, dysphasia	No intervention	Hemiparesis, dysphasia
Anda et al., 1992	57, M	Shotgun pellet	Neck	Rt angular artery	None reported	Craniotomy, embolectomy	Cerebral edema, lt lower quadrantanopia
Haselsberger & Oberbauer, 1992	9, M	Steel splinter	Neck	Rt ICA	Lt hemiparesis	EC-IC bypass	Complete recovery
Dada et al., 1993	22, M	Shotgun pellet	Chest	Rt MCA	None reported	No intervention	Death
Oser et al., 1994	40, M	Shotgun pellet	Lt neck	Lt ICA	Nonresponsive	No intervention	Residual dense rt hemiplegia, aphasia

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Authors & Year	Age (yrs), Sex	Type of Projectile	Location of Injury	Location of Migration	Symptoms of Embolus	Treatment for Embolus	Long-Term Clinical Outcome
Kuroiwa et al., 1994	27, M	Metal fragment	Lt neck	Lt MCA	Rt hemiparesis, speech disturbance, motor aphasia	Craniotomy, embolectomy	Slight rt hemiparesis, aphasia
Stein et al., 1995	21, M	Shotgun pellet	Lt chest	Proximal lt MCA	Behavioral changes	No intervention	Speech disturbance, aphasia
Jones & Tomsick, 1995	58, M	Shotgun pellet	Neck	BA	Asymptomatic	No intervention	Complete recovery
van As et al., 1995	24, M	Shotgun pellet	Head, neck	ACoA	Rt hemiparesis, speech disturbance, motor aphasia	No intervention	Mild rt hemiparesis
Cogbill & Sullivan, 1995	12, M	Shotgun pellet	Face, neck, lt chest	Lt MCA	None reported	No intervention	Complete recovery
Haninec et al., 1996	24, M	Shotgun pellet	Lt mandibular & retromandibular regions	Anterior branch of MCA	Paralysis	Craniotomy, embolectomy	Minor peripheral paresis of facial nerves
Song et al., 1999	33, M	Shotgun pellet	Neck, face	Lt MCA	None reported	Microsurgical embolectomy	Expressive dysphasia, rt hemiparesis
Yaari et al., 2000	40, M	Shotgun pellet	Neck	Lt MCA	Aphasia, rt hemiparesis	No intervention	Aphasia
Pacio & Murphy, 2002	9, M	Air gun pellet	Rt chest	Rt ICA	Rt eye blindness, nerve palsy, lt hemiparesis	Endovascular retrieval of pellet w/ balloon catheter, chemical thrombolysis	Uncal herniation, hemorrhagic infarct
David et al., 2003	30, M	Shotgun pellet	Neck, chest	Lt MCA	Rt hemiparesis, coma	No intervention	Rt arm dyspraxia
da Costa et al., 2006	76, M	Shotgun pellet	Neck	Lt SCA	Ataxia, lt hemiparesis, lt arm dysdiadochokinesia	No intervention	Mild persistent cerebellar deficit
Timpone et al., 2009	20, M	Shrapnel	Neck	Lt PCA	Neuro deficits	No intervention	Neuro deficits
Vaquero-Puerta et al., 2012	11, M	Air gun pellet	Hypopharynx, rt neck	ICA	Lt hemiplegia, positive Babinski sign	Craniotomy, embolectomy	Complete recovery
McCague et al., 2013	27, M	Shotgun pellet	Rt neck, rt chest	Rt MCA	No neuro deficits	No intervention	Complete recovery
Vedelago et al., 2014	55, M	Shotgun pellet	Rt neck, supraclavicular region	Rt MCA	Loss of gray-white matter differentiation, hypoattenuation	Craniectomy to reduce intracranial hypertension	Complete recovery
Aghaebrahim et al., 2015	9, M	Pellet	Thorax	Lt PCA	Visual field deficit	No intervention	Visual field deficit
McDowell et al., 2016	9, M	Shotgun pellet	Neck, chest, arms, abdomen, thighs	Lt PCA	Partial rt superior quadrantanopia	No intervention	Slight peripheral vision difficulty
Chen et al., 2017	30, M	Steel splinter	Rt neck	Rt MCA	Lt hemiparesis	Craniotomy, embolectomy	Complete recovery
Present study	14, M	Air gun pellet	Lt eye	Lt MCA	Rt hemiparesis, speech disturbance	EC-IC bypass following failed endovascular suction	Complete recovery

ACoA = anterior communicating artery; BA = basilar artery; EC-IC = extracranial-intracranial; neuro = neurological; PCA = posterior cerebral artery; SCA = superior cerebellar artery.

TABLE 2. Injury, symptom, and treatment characteristics

Types of Projectile	No.	Locations of Injury	No.	Locations of Migration	No.	Common Symptoms	No.	Treatments	No.	Clinical Outcomes	No.
Shotgun pellet	32	Neck	29	MCA	30	Hemiparesis or hemiplegia	23	No intervention	30	Complete recovery	12
Air gun pellet	4	Chest or thorax	19*	ICA	8	Aphasia or dysphasia	8	Surgical embolectomy	12	Neuro deficits	26
Metal fragment or steel splinter	7	Eye area	2	PCA	4	Visual field loss &/ or pupil dilation	4	EC-IC bypass	2	Death	8
Other	3	Other	3†	Other	4	Speech disturbance	3	Endovascular therapy‡	2		

One craniectomy was performed to relieve hypertension, and the patient completely recovered. This patient was not included in this chart.
* Five injuries were to both the chest and the neck, and were counted in both categories.
† One injury was to the mandibular region, and 2 were to the chest and neck as well as the face or limbs, and were counted in all relevant categories.
‡ The present case is counted twice in this chart (once as a successful EC-IC bypass and once as a failed endovascular therapy).

cess; the latter 2 have yet to be attempted on a missile embolus. Furthermore, recent improvements[5] in endovascular devices such as stent retrievers make their use in pellet embolectomy worth examining. No attempt has yet been made to use a stent retriever to remove a pellet embolus, which may allow for noninvasive embolectomy. However, the differences in material between metallic pellets and thrombi could render stent retrievers less effective; failure to remove the pellet through aspiration in our case shows that lack of malleability or manipulability of pellets may prevent endovascular removal.

An EC-IC bypass, which successfully restored cerebral blood flow in our patient, has been used in 1 other patient with MCA occlusion caused by a metal foreign object.[21] Both patients who have received EC-IC bypasses had a full neurological recovery, but this treatment is relatively novel for intracranial occlusion by a metal foreign object. More commonly, craniotomy and arteriotomy or embolectomy has been attempted (12 of 46, 26.1%; Table 3). Ten (83.3%) of the 12 patients who were treated with embolectomy had persistent neurological deficits. In our case, it was thought that direct removal of the pellet would have required temporary trapping of the M_1 segment and its associated perforators, with possible risk of direct perforator injury, and a distal bypass was chosen as a more straightforward procedure.

In previous reports, the majority of patients, even when symptomatic, have been managed conservatively with monitoring alone (30, 65.2%). However, outcomes with conservative treatment are variable, with neurological deficits reported in 15 of 30 cases (50.0%) and death in 8 (26.7%). Three of the emboli in this category that caused death were discovered only at autopsy, and 1 patient died before surgery could begin, suggesting that rapid identification and treatment of the pellet embolus may improve patient prognoses. Conservative management was also much more common before 1990 (16 of 20, 80.0%) than after (14 of 26, 53.8%), as was death related to these lesions (7 of 20 before 1990 [35.0%] and 1 of 26 after 1990 [3.8%]). This suggests that improvements in diagnostic imaging and surgical retrieval techniques may have improved early detection and allowed intervention in a wider range of cases.

Our case and literature review demonstrate the promise of EC-IC bypass to restore blood flow when an intracranial pellet embolus cannot be removed endovascularly, as well as the importance of early detection and the risks associated with conservative management. The need for surgical intervention in a given case will depend on multiple factors, including the adequacy of collateral circulation to the affected territory at risk, the exact location of the pellet, and the patient's neurological status. When collateral supply is questionable and particularly when the patient is symptomatic, we recommend attempted endovascular removal as a logical first-line option. Given the technical difficulty associated with craniotomy and embolectomy, urgent EC-IC bypass is a reasonable surgical option that has demonstrated good outcomes in 2 cases, and endovascular therapy is also worth considering due to its noninvasive nature.

Conclusions

We describe a 14-year-old boy who suffered an air gun OPI, highlighting the potential for such injuries to cause vascular fistulas and migration of a foreign body to the intracranial circulation to occlude major blood vessels. The combination of endovascular assessment with coiling and

TABLE 3. Clinical outcomes by treatment type

No Intervention, n = 30		Surgical Embolectomy, n = 12*		EC-IC Bypass, n = 2		Endovascular Therapy, n = 2†	
Outcome	No. (%)	Outcome	No. (%)	Outcome	No. (%)	Outcome	No. (%)
Complete recovery	7 (23.3)	Complete recovery	2 (16.7)	Complete recovery	2 (100)	Failure (present case)	1 (50)
Persistent neuro deficits	15 (50)	Persistent neuro deficits	10 (83.3)	Persistent neuro deficits	0 (0)	Success, neuro deficits	1 (50)
Death	8 (26.7)	Death	0 (0)	Death	0 (0)	Death	0 (0)

* One craniectomy was performed to relieve hypertension, and the patient completely recovered. This patient was not included in this chart.
† The present case is counted twice in this chart (once as a successful EC-IC bypass and once as a failed endovascular therapy).

EC-IC bypass allowed rapid repair of the CCF and restoration of blood flow to an occluded left MCA. Our case also emphasizes the importance of urgent, coordinated, neuroendovascular and neurosurgical expertise to optimize outcomes in patients with OPI.

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Disclosures

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Author Contributions

Conception and design: Nussbaum, Graupman, Goddard. Acquisition of data: all authors. Analysis and interpretation of data: Nussbaum, Kallmes. Drafting the article: all authors. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Nussbaum. Statistical analysis: Kallmes. Administrative/technical/material support: Nussbaum, Kallmes. Study supervision: Nussbaum.

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