



The Utility of Superselective Rotational Angiography for Frameless Stereotactic Navigation During Craniotomy for Micro-Arteriovenous Malformation

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■ **BACKGROUND:** Micro-arteriovenous malformations (AVMs) can present challenges to neurosurgeons with respect to localization during resection. We sought to describe a novel method that merges super-selective 3-dimensional angiographic images with magnetic resonance imaging (MRI) sequences to facilitate frameless stereotactic navigation during AVM surgery.

■ **METHODS:** A retrospective analysis was performed comprising cases that employed merging of angiographic and MRI images for navigation purposes. Baseline clinical and imaging features were recorded. The technique and operative experiences were analyzed descriptively and presented alongside detailed illustrative cases.

■ **RESULTS:** During the review period, 11 cases were identified where this technique was employed. Successful image acquisition and merging was possible in all cases. Complete obliteration of the target pathology was achieved in all cases. Precise localization of the micro-AVMs minimized dissection in eloquent cortex.

■ **CONCLUSIONS:** Superselective 3-dimensional angiographic images merged to baseline MRI sequences facilitates planning and navigation during surgery for micro-AVMs.

challenges. These lesions can be angiographically occult on initial imaging studies, particularly when associated with hemorrhage.¹⁻⁴ When craniotomy is required for definitive management, this makes localization and safe microsurgical dissection difficult. In such procedures, standard navigation (computed tomography [CT]- or magnetic resonance imaging [MRI]-based) images can fail to adequately demonstrate the pathology and succumb to artifact, hampering frameless stereotactic navigation. Superselective angiography can provide detailed images of the target pathology, but its use in stereotactic navigation has not been described. We present a novel technique using superselective 3-dimensional (3D) rotational angiography merged with conventional imaging to facilitate planning and intraoperative navigation during surgery for distal vascular pathology. With the use of this technique, navigation images during surgery highlight only the AVM vessels, allowing precise localization of the nidus.

METHODS

This study was approved by the Health Research Ethics Board at the University of Alberta (Pro00060574). A retrospective chart review was performed to identify all patients in whom digital subtraction angiography images were fused with MRI sequences for the purpose of intraoperative navigation during craniotomy for a vascular pathology. The imaging and hospital record were reviewed. Baseline characteristic, procedural details, and angiographic outcomes were recorded for descriptive analysis.

Angiographic images were acquired using a Siemens Artis biplane angiographic unit (Siemens, Munich, Germany). Processing of the angiographic images employed the Siemens Synago platform (Siemens). Merging of the digital subtraction angiography and MRI was conducted using the Stealth S7 planning station software (Medtronic, Dublin, Ireland). The Stealth S7 system also was used for intraoperative frameless stereotactic navigation.

INTRODUCTION

Distal cerebral vascular pathology, such as micro-arteriovenous malformations (AVMs) and small fusiform aneurysms, can pose diagnostic and therapeutic

Key words

- Arteriovenous malformation
- Neuronavigation
- Superselective angiography

Abbreviations and Acronyms

3D: 3-dimensional

AVM: Arteriovenous malformation

CT: Computed tomography

CTA: Computed tomography angiography

MRI: Magnetic resonance imaging

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Technique for Image Acquisition and Fusion

In most cases, superselective catheterization of the pedicles supplying the vascular lesion was undertaken. In these cases, a microcatheter hand injection was used to perform 3D rotational angiography of the dominant supply to the lesion. In one case, a pump injection through a more proximal catheter was used (not superselective).

Following image acquisition, a dual-volume 3D reconstruction was created using the Synago software. This process automatically generates 2 series of axial reference images: native (a mask acquisition consisting demonstrating bone and catheter) and subtracted (contrast only). Next, both of these series are loaded into the Stealth workstation along with a thin-cut axial T1 navigation MRI series. The subseries contains insufficient anatomical detail to merge to the MRI, necessitating a 2-step merging process. The subtracted series will, however, merge with the native series as they were obtained sequentially covering the same volume. On the Stealth work station, the native series is selected as the reference study. It can then be merged sequentially to the subtracted series and then to the MRI series. During planning and navigation, the native series is dropped and the blend function is used to simultaneously view the subtracted and MRI images. In this manner, the system displays the anatomic detail of the MRI along with the vessels directly involved in the AVM, i.e., only those opacified by the microcatheter injection. Of note, the native series used as the reference examination is not suitable for registration (default), such that the MRI must be specified as the registration examination.

Intraoperative Use

The fused image set can be used for intraoperative navigation, to assist with exposure of the target vascular pathology. Precise gyrus localization or localization within the walls of an associate hematoma can be used to minimize unnecessary dissection in critical areas and improve resection. The usual navigation concerns related brain shift; as a result, anesthesia technique and cerebrospinal fluid or hematoma drainage must be carefully considered.

RESULTS

A total of 11 patients treated between 2013 and 2019 were analyzed in this study. Eight men and three women were included, with a mean age of 39 years (range 7–56 years). Of the AVM patients, 73% (8/11) presented with hemorrhage. Two patients presented with small residual AVMs following multiple previous treatments (gamma knife radiosurgery and embolization). The AVMs were classified as micro-AVMs (less than 1 cm) in 81% (9/11) of cases. The most common location was the frontal lobe in 5 patients, and 5 patients had peri-rolandic lesions (3 frontal, 2 parietal). Of the patients with ruptured AVM, 64% (7/11) had delayed diagnosis with the malformation not evident on their initial angiographic study.

Most patients (10/11) had rotational angiography using a distal microcatheter injection. One patient had injection into the proximal posterior cerebral artery using an intermediate-type guide catheter. Partial embolization of the nidus was concurrently performed in 4 of 10 patients whose AVMs were explored with

microcatheters. Postoperative and 3- to 6-month follow-up angiography demonstrated no residual nidus or shunting. One patient experienced a delayed (2 years) recurrence of their AVM.

All rotational angiographic images were successfully merged with the preoperative MRI images using the Stealth planning station. Registration and subsequent preoperative and intraoperative navigation of the merged images was similarly successful. Surgeon-reported utility found that the merged images were helpful in craniotomy planning in most cases. Intraoperative dissection was also assisted by the navigation in many cases, although brain shift particularly in cerebellar and insular locations limited utility in this regard. In many cases, the operative surgeon reported that preoperative review of the merged images enhanced their understanding of the AVM and its relationship to the adjacent gyri and hematoma cavities.

Illustrative Cases

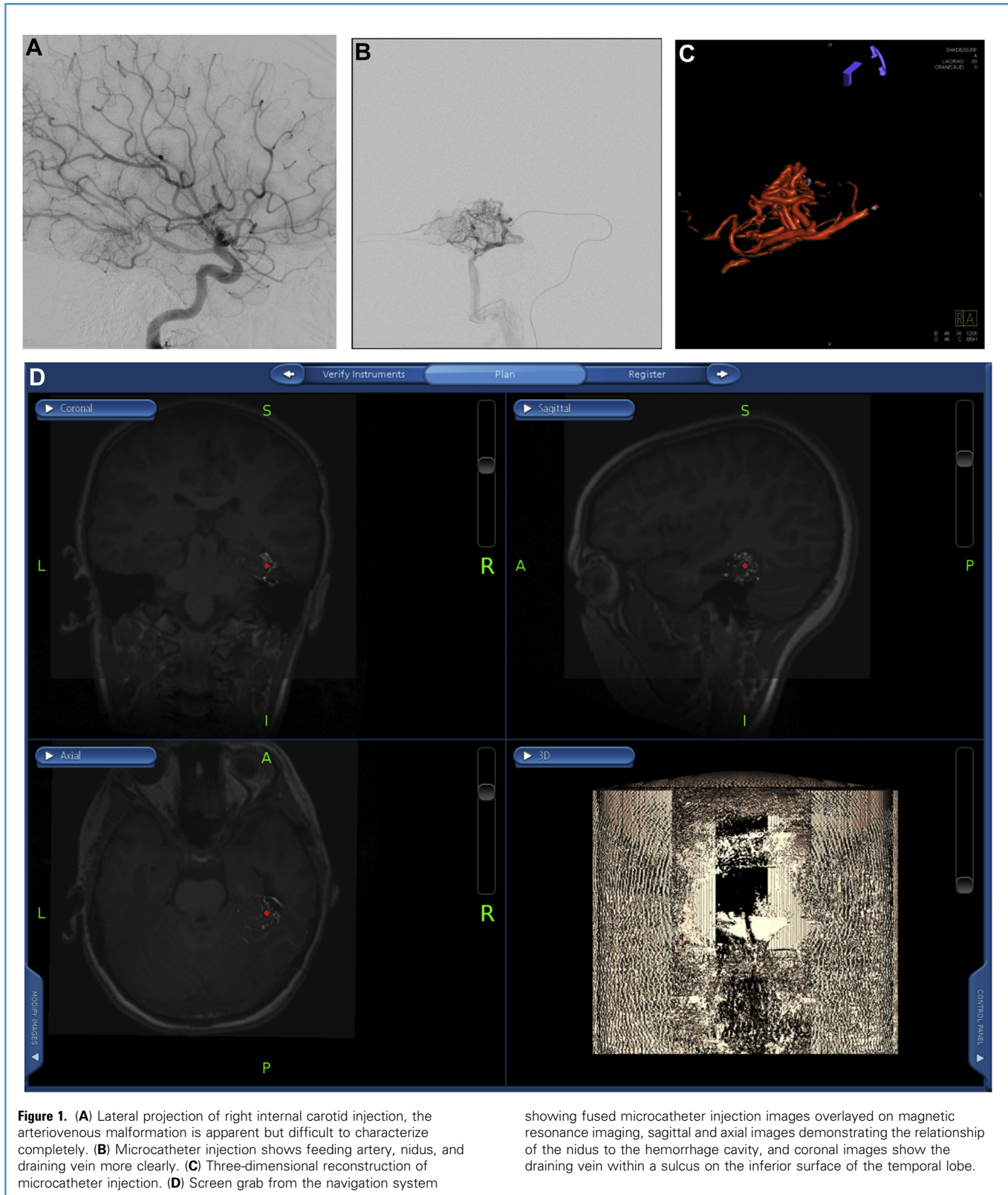
A young child presented with a right temporal intracerebral hemorrhage with intraventricular extension (Figure 1). The initial angiogram was negative but a delayed study revealed an associated AVM. The patient underwent partial embolization of the AVM before surgery. During the procedure superselective catheterization of the dominant posterior cerebral artery feeder was used to perform 3D rotational angiography. These were merged with the MRI to facilitate planning and navigation during surgery. The nidus was localized to the posterior medial portion of the hematoma cavity within the temporal lobe. This allowed a more focused surgical procedure in this young patient's dominant temporal lobe.

A patient in their fifties presented with a posterior frontal, peri-rolandic intracerebral hemorrhage (Figure 2). An initial angiogram and a second delayed angiogram were negative. The patient had a small recurrent hemorrhage in the same location, which led to a third angiogram revealing a micro-AVM. The AVM was explored for potential embolization but the superselective injections suggested en passant supply to adjacent cortex. 3D rotation angiography was performed, and the images were fused to the MRI, facilitating successful intraoperative navigation. The nidal vessels were localized to the anterior aspect of the hematoma. The precise gyrus location of the cortical vein was localized. Similar to the first case, this imaging and navigation minimized dissection and the risk of potential injury to this patient's motor cortex.

A patient in their twenties with a history of ruptured micro-AVM treated with curative embolization presented with a new intracerebral hemorrhage, remote from the previous AVM (Figure 3). Angiography diagnosed a peri-insular micro-AVM. Again, selective catheterization of the arterial feeder was performed but no embolization undertaken. Rotational images of the microcatheter injection were fused to the patient's navigation scan and used for navigation during surgery. The fused images delineated the exact location of the nidus within the insular cortex, allowing targeted opening of the Sylvian fissure and a minimal disruption of the dominant hemisphere.

DISCUSSION

This series of predominantly micro-AVMs is typical of others in the literature: all presented with hemorrhage and the majority had



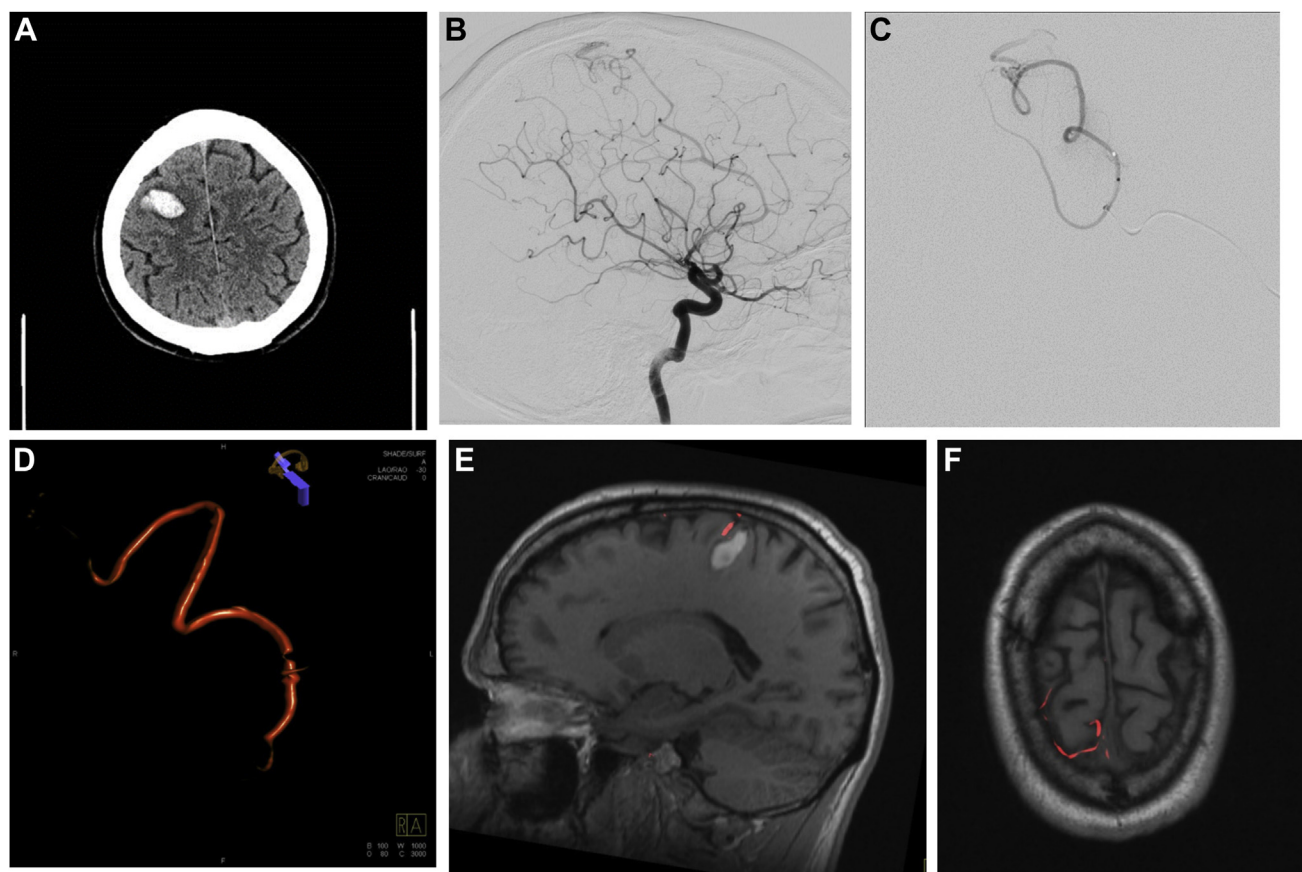


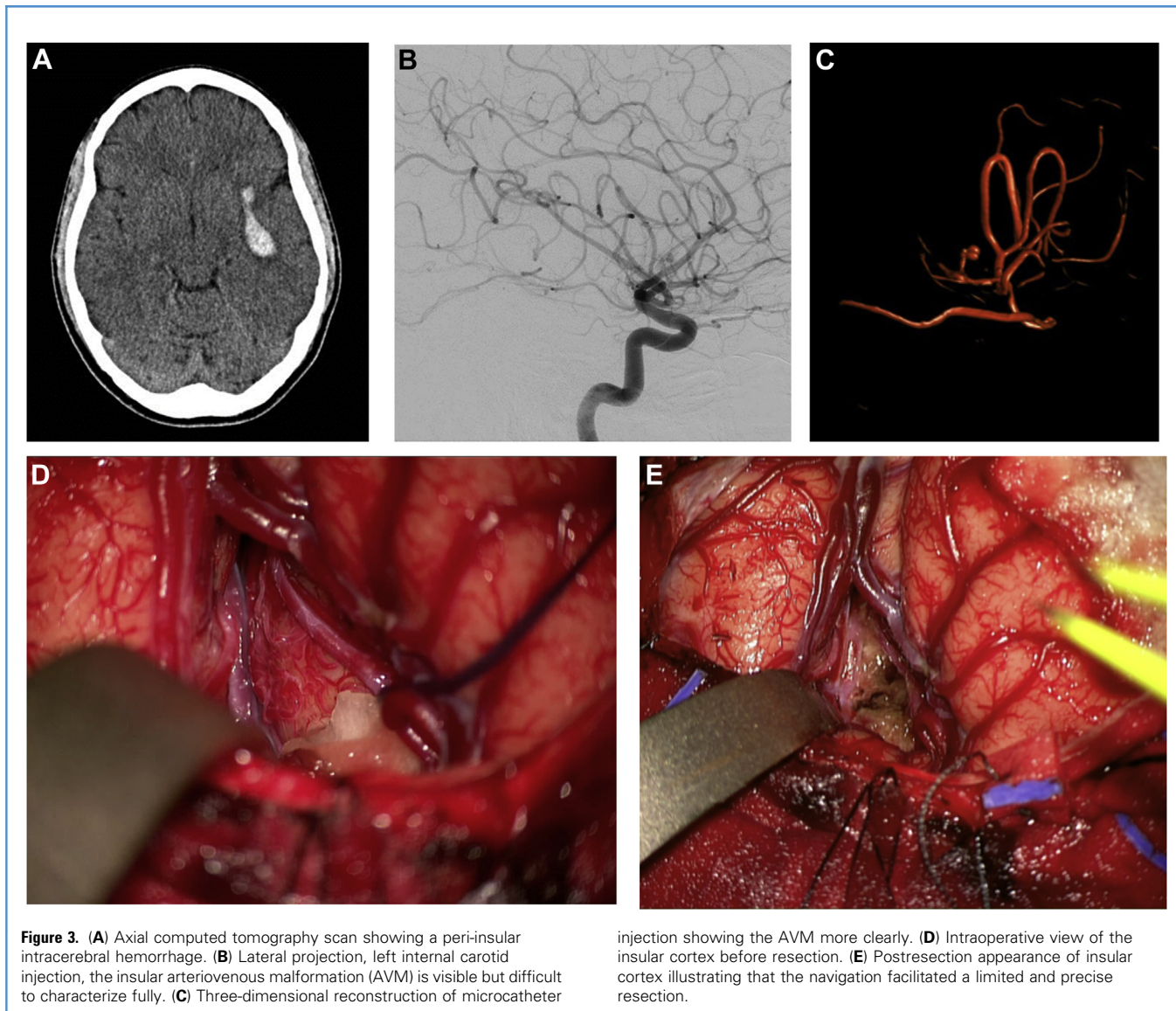
Figure 2. (A) Axial CT scan demonstrating a posterior frontal, peri-rolandic intracerebral hemorrhage. (B) Lateral projection of right internal carotid injection from the delayed angiographic study, distal arteriovenous malformation (AVM) is apparent. (C) Microcatheter injection showing AVM feeding artery and draining vein. (D) Three-dimensional reconstruction of

microcatheter injection. (E) Fused images of microcatheter injection and sagittal magnetic resonance imaging demonstrate the relationship of the nidus vessels to the intracerebral hemorrhage. (F) Fused axial images illustrate the relationship of the feeding artery and draining vein to the superficial cortical anatomy.

a delayed diagnosis.¹⁻⁴ In all patients, images derived from 3D rotational microcatheter injections were fused to the navigation MRI scan. Intraoperative navigation was successfully performed in all cases. Surgeon-rated utility of both the fused images and the navigation was high. The precise gyral location of the AVM could be pinpointed on the images. The relationship of the nidus vessels to the hematoma cavity could be precisely pinpointed. This significantly limited dissection in eloquent cortex. Finally, there were no complications related to the superselective angiography nor the intraoperative navigation.

Several authors have reported techniques to enhance intraoperative navigation and localization of small or complex arteriovenous malformations. The earliest reports used the axial source images of a conventional CT angiogram (CTA) as source images for navigation.⁵ This has particular utility in the acute setting in which the need for urgent surgical evacuation of an associated hematoma precludes diagnostic angiography. This method requires that the target pathology is easily definable on CTA, which is often not possible with relatively occult micro

AVMs. Furthermore, there can be challenges clearly distinguishing the nidus from adjacent normal vasculature on cross-sectional imaging. This technique has been further refined using the dyna CTA capabilities of modern angiography units.^{6,8} In these studies, arterial injection into the cervical circulation supplying the AVM can be used to create CT scan images with contrast enhancement of the injected vascular distribution. These images can be acquired preoperatively,⁸ or intraoperatively⁷ with the appropriate equipment and then fused to a navigation scan. The resultant fused images have shown utility for AVM localization and, in one Technical Note, for distinguishing embolic material from residual nidus.⁶ The primary disadvantage, like conventional CTA, is a lack of selectivity such that the vascular target can be obscured or difficult to differentiate from adjacent normal vessels. The generated cross-sectional images are not dissimilar to a CTA, where the nidus is relatively obscure. Further, these images will generally include bone with the potential for beam hardening artifacts interfering with identification of superficial vascular pathology.



Our experience using 3D microcatheter angiography for navigation demonstrates several important advantages for the management of micro-AVMs. Acquiring the necessary images can fit into the typical workflow for these patients. Many of these lesions are amenable to embolization with curative intent, particularly when there is a single feeder.⁴ During an embolization procedure or a diagnostic super-selective exploration, a hand injected rotational angiographic acquisition is easily obtained. If the embolization is unsuccessful or not undertaken, simple modification of the source data related to this acquisition can be merged with the patient's MRI to facilitate navigation. Furthermore, the increasing availability of hybrid operating room theaters could permit streamlining of the image acquisition and surgery, while permitting consideration of alternate vascular access, such as direct distal catheterization. Overall, this technique will allow selective

identification of the arterial feeders, nidus and draining veins without opacification of adjacent vasculature. Unlike CTA, there is little artifact from bony structures or associated embolic agents. The fused images demonstrate the relationship of the AVM to gyri and hematoma cavities which facilitates exposure and safe dissection of the malformation. This represents an important advance in the treatment of micro-AVMs which can be challenging to locate. It also assists in limiting dissection when these lesions are adjacent to eloquent cortex. Even in circumstances in which brain shift challenges navigation accuracy, preoperative review of the fused image sets enhances surgeon understanding of the relative neuroanatomical location and structure of the AVM. Finally, although not analyzed in this series, this approach can be applied to distal intracranial aneurysms (for example, mycotic aneurysms) and to larger arteriovenous malformations. Our group

has successfully applied this technique in treatment of a distal fusiform middle cerebral artery aneurysm and in identifying pedicles in a larger, more complex AVM (M. Chow and C. O'Kelly, personal communication, 2021). We are further reviewing potential utility in the planning of stereotactic radiosurgery for small inoperable AVMs.

Limitations

While the use of 3D microcatheter angiography fused to MRI for intraoperative navigation has some clear advantages, there are important limitations. First, this technology is vulnerable to the common pitfalls of neuronavigation such as brain shift and misregistration. As illustrated by one of our cases, this is particularly an issue in posterior fossa or periventricular locations. Another limitation is the requirement for superselective catheterization of the AVM pedicles. While we did not experience any complications related to this, there is a presumptive additional procedural risk. This method worked best with a single vascular pedicle. When considering the use of this method for AVMs with multiple pedicles, the current navigation platforms may struggle to handle the data processing required for fusing an increased number of series and slices.

From a methodologic perspective, this study's limited assessment of our local institutional experience cannot resolve whether

the addition of this navigation technique provides any measurable, clinically meaningful advantage. Further analysis of a larger number of patients and AVMs would help to determine the overall clinical utility. Nevertheless, we have been able to establish that 3D microcatheter angiography is safe and provides some advantage in the planning, localization, and operative resection of small and distal vascular pathology.

CONCLUSIONS

The use of 3D microcatheter angiography fused to MRI enhances resection of micro-AVMs and potentially other vascular pathology. Further study of this method in a wider, multicentered context would be informative regarding impact on successful obliteration rates and clinical outcomes.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Cian J. O'Kelly: Conceptualization, Methodology, Software, Investigation, Data curation, Writing — original draft, Writing — review & editing. **Jeremy Rempel:** Methodology, Software, Writing — review & editing. **Rob Ashforth:** Methodology, Software. **Tim Darsaut:** Conceptualization, Writing — review & editing. **Michael Chow:** Conceptualization, Methodology, Software, Investigation, Writing — review & editing.

REFERENCES

- Alen JF, Lagares A, Paredes I, et al. Cerebral microarteriovenous malformations: a series of 28 cases. *J Neurosurg.* 2013;119:594-602.
- Cellerini M, Mangiafico S, Villa G, et al. Cerebral microarteriovenous malformations: diagnostic and therapeutic features in a series of patients. *AJNR Am J Neuroradiol.* 2002;23:945-952.
- Perrini P, Cellerini M, Mangiafico S, Di Lorenzo N. Superselective angiography increases the diagnostic yield in the investigation of intracranial haematomas caused by micro-arteriovenous malformations. *Neurol Sci.* 2004;25:241-242.
- Perrini P, Scollato A, Cellerini M, et al. Results of surgical and endovascular treatment of intracranial micro-arteriovenous malformations with emphasis on superselective angiography. *Acta Neurochir (Wien).* 2004;146:755-766.
- Coenen VA, Dammert S, Reinges MH, Mull M, Gilsbach JM, Rohde V. Image-guided micro-neurosurgical management of small cerebral arteriovenous malformations: the value of navigated computed tomographic angiography. *Neuroradiology.* 2005;47:66-72.
- Gonzalez LF, Albuquerque FC, Boom S, Burling BS, Papadopoulos SM, Spetzler RF. Image-guided resection of embolized cerebral arteriovenous malformations based on catheter-based angiography. *Neurosurgery.* 2010;67:471-475.
- Raza SM, Papadimitriou K, Gandhi D, Radvany M, Olivi A, Huang J. Intra-arterial intraoperative computed tomography angiography guided navigation: a new technique for localization of vascular pathology. *Neurosurgery.* 2012;71(2 Suppl Operative): ons240-ons252 [discussion: ons252].
- Tee JW, Dally M, Madan A, Hwang P. Surgical treatment of poorly visualised and complex cerebrovascular lesions using pre-operative angiographic data as angiographic DynaCT datasets for frameless stereotactic navigation. *Acta Neurochir (Wien).* 2012;154:1159-1167.

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