Published in final edited form as:

World Neurosurg. 2018 November ; 119: e1041–e1051. doi:10.1016/j.wneu.2018.08.074.

Contralateral Transfalcine Versus Ipsilateral Anterior Interhemispheric Approach for Midline Arteriovenous Malformations: Surgical and Anatomical Assessment

Sergio García-García^{2,3}, José Juan González-Sánchez², Sirin Gandhi¹, Halima Tabani³, Ali Tayebi Meybodi¹, Sofia Kakaizada³, Michael T. Lawton¹, Arnau Benet¹

¹Department of Neurosurgery, Barrow Neurological Institute, Phoenix, Arizona, USA

²Department of Neurosurgery, Hospital Clinic, Barcelona, Spain

³Department of Neurosurgery, University of California, San Francisco, California, USA

Abstract

BACKGROUND: The contralateral anterior interhemispheric approach (CAIA) is considered to provide surgical advantages to access deep midline lesions: wider working angle, gravity enhanced dissection and retraction, more efficient lighting, and ergonomics. Our team has previously published on the merits of using a contralateral trajectory for medial frontoparietal arteriovenous malformations (AVMs) compared with the conventional anterior interhemispheric approach (IAIA). In this article, we compare the IAIA and CAIA for the resection of medial frontoparietal AVMs using quantitative surgical and anatomical analysis.

METHODS: Two models were designed mimicking the most common features of midline AVMs. The CAIA and IAIA were performed bilaterally in 10 specimens. Variables to compare technical feasibility (surgical window [SW] and surgical freedom [SF], target exposure, and angle of attack) were independently assessed using stereotactic navigation. The average SW, SF, and angle of attack were compared with the Student *t* test. Significance threshold was set at 0.05.

RESULTS: The CITA and IAIA were similar in terms of SW, target exposure, and SF in the superior aspect of the AVM. In the depth of the interhemispheric fissure, the CAIA was significantly superior to IAIA in both AVM models: 77% wider AA for the inferior aspect of the AVM ($P < 0.01$) and greater SF for the draining vein (54%, $P = 0.01$), ipsilateral (98%, $P = 0.02$), and contralateral ACA (117%, $P < 0.01$).

CONCLUSIONS: This study suggests technical superiority of the CAIA for the resection of deep midline AVMs. No objective difference was noted in the superficial areas of our models, denoting that IAIA is a safer choice for superficial AVMs. Our results set the foundation for further clinical analysis comparing both approaches.

To whom correspondence should be addressed: Sergio García-García, M.D. [iskender_brave@hotmail.com].

Conflict of interest statement: The authors declare that the article content was composed in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Keywords

Arteriovenous malformation; Contralateral; Interhemispheric; Ipsilateral; Midline; Surgical freedom; Surgical simulation

INTRODUCTION

Neurosurgical procedures along the interhemispheric fissure (IF) harbor unique features differentiating them from those lesions located at the surface of the cerebral convexity and the midline.^{1,2} The falx, bridging veins,³ and a limited angle of attack (AA) narrow the surgical corridor and result in an obscured exposure of the medial surface of the cerebral hemisphere.^{4,5}

Deep midline arteriovenous malformations (AVMs) pose a challenge to the cerebrovascular surgeon as the feeding arteries (FAs) run deep in the IF, the surgical corridor is narrow, highly eloquent areas may surround the nidus, and the access to the lateral margins of the AVM might be extremely difficult.⁶ The main FAs of these AVMs arising from the anterior and posterior cerebral arteries also are exposed later during the dissection.⁴ These AVMs may have bilateral arterial supply as the FA might cross midline.^{4,7-9} It is critical to achieve early exposure of the FAs as well as preserve the en passage arteries supplying the brain distal to the AVM. In addition, the medial hemisphere hosts highly eloquent areas such as the sensorimotor and visual cortices, which could be bilaterally endangered during the removal of AVMs. Hence, surgical steps such as brain retraction and circum-dissection of the nidus should be optimized to avoid functional sequelae.

The classic interhemispheric approach to deep-seated medial AVMs requires active retraction to expose the medial side of the conceptualized cube that represents an AVM.¹⁰ This retraction reaches its maximum as the dissection progresses laterally. In an attempt to improve the working angle and to minimize potentially harmful maneuvers during the removal of midline intra-axial lesions, a contralateral anterior interhemispheric (transfalcine) approach (CAIA) has been suggested.¹¹ Our team has previously published a retrospective clinical series demonstrating clinical superiority of the CAIA over the ipsilateral anterior interhemispheric approach (IAIA) for deep AVMs.⁶

Some reports have highlighted the potential benefits of the CAIA for deep midline lesions: gravity-enhanced dissection and retraction; wider working angle; better ergonomics; and more efficient lighting.^{12,13} These advantages add up to AVM-specific conditions: draining veins (DVs) are less likely to block the surgical corridor; the nidus is delivered within the optical scope by gravity; and the main FAs are reached without mobilizing the nidus. The empirical support of these statements is inferred from certain surgical reports.^{2,6,11,14} Our group has previously reported clinical examples of the use of a contralateral approach for vascular lesions with favorable outcomes.^{6,12,15} Nonetheless, doubts may arise imputing the good outcomes in the available reports to the expertise of outstanding neurosurgeons. As objective scientific and anatomic evidence of the superiority of the CAIA over the IAIA is scarce, some surgeons may not adopt a contralateral trajectory.

The present study is designed to assess the potential benefits of CAIA over IAIA for the resection of deep midline frontoparietal AVMs. A comparative assessment was conducted through surgical simulation in cadavers to analyze surgical parameters for each approach, including surgical window (SW), exposure obtained, and surgical freedom (SF), to evaluate which approach was better for accessing deep frontoparietal midline AVMs. We sought to provide recommendations for optimal surgical strategy based on the findings of the morphometric and surgical analyses.

METHODS

Six heads (12 specimens) were prepared for surgical simulation using our customized formula for embalming.¹⁶ A preliminary surgical simulation was conducted in 2 specimens to design the research protocol. Anatomic dissections were performed under an operating microscope (Pentero 800; Carl Zeiss, Oberkochen, Germany). Magnetic resonance images (3-T, T1-weighted) were acquired, uploaded to the navigation system (Stryker, Kalamazoo, Michigan, USA), and registered to the specimen.

Two AVM models were created to simulate the most common features of interhemispheric AVMs (Figure 1A and B). The features of these AVMs were empirically established to an approximate nidus size of 3 cm and a single DV directed to the superior sagittal sinus (SSS) through different trajectories (anterior border of AVM and center of the corridor). Once the approach was performed, the models were implanted with the nidus centered in the depth of the IF respecting the bridging vein (BV) patterns. The AVM was placed in the IF after we retracted the ipsilateral cortex without parenchymal removal or distorting the anatomy. The inferior edge of the model was set to be in contact with the ipsilateral pericallosal artery. If needed for implantation, the BVs were cut and reanastomosed. Morphometric analysis was independently conducted for 2 drainage settings in every specimen—one with the DV lying in the anterior border of the surgical corridor emptying into the SSS (AVM1) and another independent one with the DV lying in the center of the surgical corridor, also draining into the SSS (AVM2). AVMs models were the same in the superior-inferior axis and comparable in surface (Figure 1A and B).

To simulate brain shift caused by gravity and cerebrospinal fluid release, we established a maximal superficial opening of the IF of 2 cm. This retraction was inferred from published studies that assessed brain shift in surgical procedures and laboratory research.^{17–19} If the superficial tension of the retraction risked disrupting the integrity of the BV or the parenchymal surface, the superficial opening was lowered to that threshold.

Approaches

Ipsilateral Anterior Interhemispheric Approach.—The heads were fixed in a 3-pin head holder (Mizuho America, Union City, California, USA) tilted 45° upward and rotated to orient the midline horizontally, parallel to the floor with neutral flexion. In this setting, the AVM would lie down, in the dependent hemisphere, allowing gravity to assist the opening of the IF (Figure 2A). An inverted U-shaped incision exposing the coronal suture and crossing the midline was performed. The flap was reflected downward. A square-shaped 6 × 6-cm craniotomy was performed, 1 cm anterior to the coronal suture and 1 cm beyond the midline.

Dura was opened in a U-shaped fashion based medially (Figure 3). Microscopic interhemispheric dissection was conducted to expose the cingulate gyrus, corpus callosum, and both pericallosal arteries, if possible.

Contralateral Anterior Interhemispheric (Transfalcine) Approach.—For the contralateral approach, the heads were tilted 60° instead of 45, maintaining the midline parallel to the floor⁴ (Figure 2B). In this setting, the hemisphere containing the AVM was placed up, enhancing the assistance of gravity to dissect the IF from the unaffected hemisphere and facilitating nidal microdissection. Brain retraction was kept the same as in the IAIA. A falcine window was opened 5 mm below the inferior border of the SSS and as far in the sagittal plane as surgically feasible. The inferior sagittal sinus (ISS) was ligated. The area of this falcine window was measured (Figure 1D).

Variables

For each specimen, the number of BVs, the length of the SSS free of BVs, and the total retraction obtained (amount of displacement from the midline, in cm) were measured and recorded. The SW, defined as the polygonal area (cm²) that superficially limits and contains the surgical corridor, was recorded for each approach and model. In both approaches, the SW was limited by BVs, and in the case of the IIA also by the DVs. The SW was outlined using the neuronavigation system, acquiring with the probe the coordinates of the structures limiting the corridor (Figure 1C).

The exposure of the target (the AVM model) was evaluated for each approach. This was achieved by assessing the accessibility to 4 defined points on each model: the most superior, inferior, posterior, and anterior vertex of the irregular polygon representing the medial surface of the AVM (Figure 1A and B). The area delimited by these points on the AVM was measured using the navigation system before the implantation. The maximal exposed area, meaning the most superior, inferior, anterior, and posterior points of the model accessed with each approach, was calculated. These 2 areas were compared and the ratio was expressed in percentage.

The maximal angular range from lateral to medial within the coronal plane was defined as the AA. The AA at the most superior and inferior points within the AVM were measured swiveling the navigation probe in the coronal plane for each approach and model.

SF, or the objective representation of how freely an instrument can be moved around a particular target, expressed in cm², also was assessed^{20–22} for each approach and model. Critical landmarks were defined in the AVM and the IF as targets to evaluate the SF for both approaches. These included the point in the superior edge of the AVM, the origin of the DV, and both pericallosal arteries at their nearest points to the AVM. A 10-cm straight probe was held over each of these targets and then swiveled within the outline of the SW. Each major change in the trajectory was recorded, registering it with the navigation probe and thus, obtaining a set of tri-axial coordinates. When one of these defined points could not be exposed, the SF at that point was considered zero (Figure 2C and D).

The geocentric Cartesian X, Y, Z coordinates provided by the navigation system were recorded and processed using a software named Surface Area Calculator (Bitwise ideas, Inc, Ottawa, Ontario, Canada) to obtain the areas for SW, target exposure, and SF.

Statistical Analysis

The measurements obtained were processed and analyzed using SPSS, version 20 (IBM Corp., Armonk, New York, USA). Normal distribution of every variable was assessed using the Kolmogorov–Smirnov and Shapiro–Wilk tests. Once confirmed, the normal distribution of data sets, variables were compared using a parametric test. An unpaired Student *t* test was implemented to compare the means of dependent continuous variables (SW, SF, and AA) in both approaches. A confidence interval of 95% and $P < 0.05$ were established to reach statistical significance.

RESULTS

Morphometrics

The total surface area of the AVM models “AVM1” and “AVM2” was 3.67 and 3.29 cm², respectively. The mean length of the SSS free of BV was 5.3 cm (SD = 3.7). The number of BVs ranged between 1 and 3 (mean = 1.5, SD = 1). The mean retraction was 1.65 cm (SD = 0.2). The falx was opened to create an average window of 18.4 cm² (SD = 0.4).

Dependent Variables

Normal distribution of analyzed variables was confirmed (Table 1). For the superior aspect of the AVM, the IAIA and CAIA offered a similar SW, target exposure, and SF ($P > 0.05$). The ease of access to the AVM in the depth of the IF was significantly superior for CAIA than for IAIA. The CAIA provided a wider AA for the inferior aspect of the AVM ($P < 0.01$) (Figure 4), greater SF for the DV (AVM1 $P = 0.02$; AVM2 $P < 0.01$), and for both the ipsilateral (AVM1 $P < 0.01$; AVM2 $P = 0.02$) and contralateral (AVM1 $P < 0.01$; AVM2 $P < 0.01$) anterior cerebral arteries (ACAs) (Figure 5). These results were consistent for both the AVM models. However, the CAIA offered a wider AA than the IAIA in the superior aspect of the AVM 1 but not in the AVM 2. Compared with the IAIA, the AA for CAIA in the inferior point increased 77% for AVM1 and in 64% for AVM2. Likewise, CAIA offered an increased SF in the ACA (range: 89%–141%) and the DV (42%–66%) compared with IAIA. These results are summarized in Table 2.

Illustrative Case 1 (IAIA)

A 57-year-old female patient was diagnosed with an unruptured right medial frontal AVM after presenting to the hospital with one episode of syncope and persistent bifrontal headache. Preoperative angiogram revealed that the AVM measured $2.1 \times 1.4 \times 2.4$ cm and had arterial feeders from the right pericallosal and right callosomarginal arteries. The AVM had both superficial and deep venous drainage via median cortical vein and callosal vein. The Spetzler–Martin grade was 2 and the supplementary Lawton–Young grade was 4. This AVM extended 1.5 cm laterally from the midline in its widest portion and was 4.9 cm deep from the cortical surface (Figure 6A and B).

The AVM was resected through an IAIA. After opening the IF, the pericallosal vessels were exposed running over the corpus callosum. After we dissected the FAs, a circumferential plane was developed around the nidus. The DVs were detached and the nidus was removed. Postoperative angiogram demonstrated a tiny residual shunting nidus measuring 5 mm (Figure 6C and D). The patient was taken back to the operating room for retreatment of the remainder of the AVM. The resection cavity was explored, and a small tuft of residual AVM was identified in the lateral and inferior aspect of the cavity. The AVM was successfully resected. Postoperatively, the patient had no residual AVM nidus and presented with no new neurologic deficit (Figure 6E and F).

Illustrative Case 2 (CAIA)

A 55-year-old man with a history of developmental venous anomaly presented to the hospital with multiple episodes of generalized tonic–clonic seizures and was diagnosed with an unruptured right medial frontal AVM. Preoperative angiogram confirmed these findings and demonstrated arterial feeders from the right pericallosal, callosomarginal and frontopolar arteries. The AVM had superficial venous drainage via the median cortical vein (Figure 7A and B). The Spetzler–Martin grade was 2 and the supplementary Lawton–Young grade was 4. This AVM extended 1.9 cm laterally from the midline and was 5.3 cm deep to the cortical surface.

The patient underwent surgical resection of this lesion through the CIA. After we opened the IF, subarachnoid dissection was carried down to the corpus callosum and the falx was transected. The FAs were identified and then cauterized from a distal to proximal direction. A plane around the AVM was gradually developed while preserving the DVs. After circumferential dissection and delivery of the nidus into the IF, the DVs were cut and the nidus was removed. Postoperative angiogram revealed no residual AVM nidus (Figure 7C and D). The patient reported no new neurologic deficits and made an excellent recovery.

DISCUSSION

The present study states the surgical superiority of the CAIA over the IAIA for the resection of deep midline AVMs. Our cadaveric simulation provided objective data to assess the indications for the optimal technique (IAIA or CAIA) for safe and successful surgical removal of midline AVMs. The results proved that the CAIA offers a wider AA, greater ease, and increased SF to access the depth of the IF. This superiority vanished for the superficial aspect of the IF, where both surgical options were comparable.

AVMs located deep in the IF are challenging entities that require thoughtful planning of surgical strategy and careful management. Such lesions are routinely accessed using the IAIA.^{6,23} However, some authors have suggested approaching midline tumors and vascular lesions through a contralateral trajectory.^{2,6,11,12,14,24} However, there is a lack of objective clinical and surgical evidence of the advantages of this procedure over the IAIA. Our positive experience with the CAIA^{6,12,15} encouraged us to provide recommendations for optimal indication of this approach based on anatomical evidence.

Although a contralateral approach had been previously implemented for various neurosurgical lesions,^{25,26} its use for midline AVMs was first reported by Machado de Almeida et al.¹¹ in 1984. They outlined how advantageous, in terms of working angle and surgical comfort, the contralateral approach was compared to the ipsilateral approach. As discussed by the authors, whether the approach was contra- or ipsilateral, the use of fixed retractors and the sitting or semi-sitting position were essential in that early microsurgical era.^{27–30} Growing concern about the potential complications (e.g., brain edema or injury, air embolism, pneumocephalus, etc.)^{31–33} of those established techniques led to a progressive and firm transition toward the use of dynamic retraction³⁴ and/or retractorless surgery. This has been supplemented through technological advances and the modifications in patient positioning, neuroanesthesia, and microsurgical techniques.^{12,13,35,36} The quest for optimizing every surgical tenet led to adopt contralateral trajectories for deep-seated lesions.

CAIA Versus IAIA

The CAIA enhances some anatomical, morphologic, and surgical features to improve the access to deep midline structures. In a contralateral approach, the surgical trajectory to a deep midline target is switched from tangential to perpendicular, thus providing a more comfortable angle for dissection. As shown in case 2, a wider AA expands the dissection to the lateral and deep margins of the AVM. The lateral boundary is probably the most difficult part to access from an IAIA, as lenticulostriate perforators may feed the AVM from lateral to medial,¹⁰ resulting in partial removal of the AVM as shown in case 1. Similarly, a greater maneuverability in the depth of the IF ensures a better control of feeders arising from both ipsi- and contralateral ACAs.^{7,9,10} Our results have brought evidence for supporting the validity of CAIA as an efficient and more comfortable way to access deep midline AVMs.

AVMs located near the midline in the convexity, namely paramedian AVMs, are approached perpendicularly from an ipsilateral trajectory.^{4,10} If we conceptualize an AVM as a cube, the IAIA would directly expose the superficial plane of the AVM and with minimal retraction we could access the side facing the IF. In addition, the dissection could be addressed both to the convexity, to control FAs ascending from the middle cerebral artery; and to the IF to suppress the supply coming from the ACA or the posterior cerebral artery. Superficial AVMs are less likely to have deep DV^{4,9} that could compromise the effectiveness of an IAIA. Our results support the idea of approaching superficial midline AVMs from an IAIA, as no advantages were found in terms of SF or AA in the superior aspect of our model and thus, just one hemisphere is endangered.

The superficial draining pattern in superficial midline AVMs might make gravity retraction unnecessary⁴ but in the case of deeper AVMs, the assistance of gravity in retracting the interhemispheric corridor is essential. In CAIA, gravity assists the surgical procedure during the opening of the IF by pulling down the nonlesional hemisphere and delivering the nidus into the IF as the dissection progresses, which could minimize retractor-induced edema.^{12,13,37} In addition, in the CAIA, the superficial DV ascending within the IF to the SSS is protected by the falx, whereas it might hamper the dissection of the nidus in the IAIA.

Despite the significant benefits of a contralateral trajectory, the CAIA should be carefully selected considering the features of the AVM and patient's anatomy. CAIA exposes and

endangers both hemispheres to surgical manipulation and increases the risk of injury of the unaffected hemisphere. The CAIA mandates an additional surgical step of cutting the falx, which has been safely and extensively conducted for other indications.^{1,2,11,14,24} Nonetheless, the falx may host meningeal vessels or venous lacunae that could make this step more difficult.³⁸ To avoid unfavorable events in this moment of the surgery, we suggest cutting the falx layer by layer and retracting the falx away from the nidus.⁶ However, this step carries a small risk of damaging the DV or the nidus if the opening is narrow or if the AVM is firmly attached to the dura. It is also important to note that few cingulate AVMs might drain into the pericallosal veins¹⁰ and thereon to the ISS. If there is a prominent ISS or the main vein of the AVM drains into it, then primary ligation of the ISS should be avoided. This could lead to potential narrowing of the SW for a CAIA. It has been conjectured that a contralateral bleeding in the context of a midline approach would be more difficult to control through a contralateral trajectory.³⁹ However, our results suggest that CAIA provide better control of the main vascular structures (DVs and bilateral ACAs), commonly involved in treacherous bleedings in the setting of an AVM resection.

Additional factors may impact the choice of the side of approach, ipsi or contralateral. The existence of an extensive pattern of BVs may extremely constrain the approach. Some of the BVs might be safely untethered; nonetheless, there may be BV or venous lacunae that should be preserved to ensure an appropriate venous drainage of the hemisphere. This prominent ipsilateral superficial draining pattern would negatively impact the SW and corridor for IAIA rather than CAIA. A deep venous drainage pattern would not actually constrain the surgical access to the AVM, as it would not obstruct the dissection through a CAIA.¹⁰ Nevertheless, as inferred from our results, the CAIA widens the AA as the dissection deepens into the IF. This fact contributes to better approach the veins draining into the deep venous system that should, indeed, be addressed at the end of the dissection. The selection of the approach should avoid jeopardizing intact eloquent areas and take advantage of the pathways created by the disease. Thus, in case of a ruptured AVM with a superficial hematoma, the dissection could be better addressed through the injured parenchyma.

Surgical Simulation Model

The designed surgical model accounts for the main features of the surgical strategy for safe removal of deep midline AVM. The selected surgical variables (SW, SF, and AA) have been previously implemented in surgical simulation studies, allowing us to compare different techniques and offering useful information for the selection of target-tailored approaches.^{20,21,40–42} The selected targets within the AVM and the IF (ACA ipsi- and contralateral) illustrate the main structures to be aimed during an AVM resection.^{4,10} The AVM model was created considering the main and most common features of the medial frontoparietal malformations.^{4,9,10}

Nonetheless, the model may misrepresent some of the surgical tenets needed for AVM resection. A large number of possible configurations of FAs, sizes, and draining patterns exists. As an example, the posterior cerebral artery often is involved in the supply of midline parietal AVMs, but as these arteries also run in a variable depth within the IF, our model may be representative of an AVM fed by the posterior cerebral artery. Although the present study

does not assess the operability for all possible settings of AVM (nidus size, feeders, DV, location, etc.), the surgical model illustrates the superiority of the CAIA over the IAIA for an unpredictable SW; a variable falx size and IF depth. In addition, the results are consistent for 2 different AVM models, similar in planar size but different in shape, volume, and draining pattern.

Study Limitations

Because this research uses a surgical simulation model in cadavers, there are several limitations to its application in surgery. These limitations include unaffected morphology, brain stiffness, and the lack of brain relaxation and gravity-assisted retraction. Our customized embalming formula offers a consistency profile close to the unfixed brain, hence, reducing the impact of these cadaveric simulation shortcomings.¹⁶ We used specimens without structural lesions to ensure reliability when comparing surgical approaches. However, the anatomical distortions related to a ruptured or unruptured AVM might not be properly represented. Even though the AVM model obstructs the surgical corridor with a bulging ascending vein and a volume occupying the IF, it cannot reproduce the surgical experience of a pulsatile vascular structure that changes its morphology as the dissection advances. The retraction applied (1.65 cm) was inferred from studies assessing brain shift through cortical displacement.^{17–19} This retraction is probably inferior to that obtained through brain relaxation, cerebrospinal fluid release, gravity, and untethered BV. However, this does not affect the results of our study, as the comparative analysis was performed on similar cadaveric heads in both approaches. The present study sets the basis for future research in surgical treatment of AVMs that could implement advanced simulation models through 3D printing and artificial perfusion among others.

CONCLUSIONS

The present study compared the capacity provided by contralateral and ipsilateral trajectories to approach midline AVMs located within the IF. The CAIA is a better option to access and remove deep midline frontoparietal AVMs. The results of our surgical simulations provide objective evidence of the superiority of the CAIA versus IAIA in terms of SF and AA. This greater surgical easiness becomes especially advantageous in the dissection of the lateral boundaries of a midline AVM, the most challenging and hazardous step of the procedure. The clinical implications of these findings should be validated in a comparative analysis of case series operated through these different approaches.

ACKNOWLEDGMENTS

We express our sincere gratitude to the body donors and their families, who, through their altruism, this project was made possible. We also thank Kenneth X. Probst for the excellent illustration.

Abbreviations and Acronyms

AA	Angle of attack
ACA	Anterior cerebral artery

AVM	Arteriovenous malformation
BV	Bridging vein
CAIA	Contralateral Anterior Interhemispheric Approach
DV	Draining vein
FA	Feeding artery
IAIA	Ipsilateral Anterior Interhemispheric Approach
IF	Interhemispheric Fissure
ISS	Inferior sagittal sinus
SF	Surgical freedom
SSS	Superior sagittal sinus
SW	Surgical window

REFERENCES

1. Quinones-Hinojosa A, Chang EF, Chaichana KL, McDermott MW. Surgical considerations in the management of falcotentorial meningiomas: advantages of the bilateral occipital transtentorial/transfalcine craniotomy for large tumors. *Neurosurgery* 2009;64(5 suppl 2):260–268 [discussion: 268]. [PubMed: 19287325]
2. Goel A Transfalcine approach to a contralateral hemispheric tumour. *Acta Neurochir (Wien)* 1995; 135:210–212. [PubMed: 8748818]
3. Fahlbusch R, Keller B, Ganslandt O, Kreutzer J, Nimsky C. Transsphenoidal surgery in acromegaly investigated by intraoperative high-field magnetic resonance imaging. *Eur J Endocrinol* 2005;153: 239–248. [PubMed: 16061830]
4. Kim YB, Young WL, Lawton MT, Project UBS. Parafalcine and midline arteriovenous malformations: surgical strategy, techniques, and outcomes. *J Neurosurg* 2011;114:984–993. [PubMed: 21250805]
5. Du R, Young WL, Lawton MT. “Tangential” resection of medial temporal lobe arteriovenous malformations with the orbitozygomatic approach. *Neurosurgery* 2004;54:645–651 [discussion: 651–642]. [PubMed: 15028139]
6. Burkhardt JK, Winkler EA, Lawton MT. Contralateral posterior interhemispheric approach to deep medial parietooccipital vascular malformations: surgical technique and results. *J Neurosurg* 2018;129:198–204. [PubMed: 28731396]
7. Martin NA, Wilson CB. Medial occipital arteriovenous malformations. Surgical treatment. *J Neurosurg* 1982;56:798–802. [PubMed: 7077379]
8. Picard L, Miyachi S, Braun M, Bracard S, Per A, Marchal JC. Arteriovenous malformations of the corpus callosum—radioanatomic study and effectiveness of intranidus embolization. *Neurol Med Chir (Tokyo)* 1996;36:851–859 [discussion: 858–859]. [PubMed: 9002712]
9. Stein BM. Arteriovenous malformations of the medial cerebral hemisphere and the limbic system. *J Neurosurg* 1984;60:23–31. [PubMed: 6689724]
10. Lawton MT. Seven Arteriovenous Malformations: Tenets and Techniques for Resection New York: Thieme; 2014.
11. Machado de Almeida G, Shibata MK, Nakagawa EJ. Contralateral parafalcine approach for parasagittal and callosal arteriovenous malformations. *Neurosurgery* 1984;14:744–746. [PubMed: 6462412]

12. Chi JH, Lawton MT. Posterior interhemispheric approach: surgical technique, application to vascular lesions, and benefits of gravity retraction. *Neurosurgery* 2006;59(1 suppl 1):ONS41–ONS49 [discussion: ONS41–ONS49]. [PubMed: 16888550]
13. Spetzler RF, Sanai N. The quiet revolution: retractorless surgery for complex vascular and skull base lesions. *J Neurosurg* 2012;116:291–300. [PubMed: 21981642]
14. Malekpour M, Cohen-Gadol AA. Interhemispheric transfalcine approach and awake cortical mapping for resection of peri-atrial gliomas associated with the central lobule. *J Clin Neurosci* 2015;22:383–386. [PubMed: 25304435]
15. Benet A, Griswold D, Tabani H, Rubio RR, Yousef S, Meybodi AT, et al. Contralateral anterior interhemispheric approach to medial frontal arteriovenous malformation: 3-dimensional operative video. *Oper Neurosurg (Hagerstown)* 2018;14:86. [PubMed: 28521028]
16. Benet A, Rincon-Torroella J, Lawton MT, Gonzalez Sanchez JJ. Novel embalming solution for neurosurgical simulation in cadavers. *J Neurosurg* 2014;120:1229–1237. [PubMed: 24527814]
17. Roberts DW, Hartov A, Kennedy FE, Miga MI, Paulsen KD. Intraoperative brain shift and deformation: a quantitative analysis of cortical displacement in 28 cases. *Neurosurgery* 1998;43:749–758 [discussion: 758–760]. [PubMed: 9766300]
18. Letteboer MM, Willems PW, Viergever MA, Niessen WJ. Brain shift estimation in image-guided neurosurgery using 3-D ultrasound. *IEEE Trans Biomed Eng* 2005;52:268–276. [PubMed: 15709664]
19. Hadani M, Spiegelman R, Feldman Z, Berkenstadt H, Ram Z. Novel, compact, intraoperative magnetic resonance imaging-guided system for conventional neurosurgical operating rooms. *Neurosurgery* 2001;48:799–807 [discussion: 807–799]. [PubMed: 11322440]
20. Benet A, Hervey-Jumper SL, Sanchez JJ, Lawton MT, Berger MS. Surgical assessment of the insula. Part 1: surgical anatomy and morphometric analysis of the transsylvian and transcortical approaches to the insula. *J Neurosurg* 2016;124:469–481. [PubMed: 26339854]
21. Schwartz MS, Anderson GJ, Horgan MA, Kellogg JX, McMenomey SO, Delashaw JB Jr. Quantification of increased exposure resulting from orbital rim and orbitozygomatic osteotomy via the frontotemporal transsylvian approach. *J Neurosurg* 1999;91:1020–1026. [PubMed: 10584849]
22. Gagliardi F, Boari N, Roberti F, Caputy AJ, Mortini P. Operability score: an innovative tool for quantitative assessment of operability in comparative studies on surgical anatomy. *J Craniomaxillofac Surg* 2014;42:1000–1004. [PubMed: 24530083]
23. Hafez A, Raygor KP, Lawton MT. Contralateral anterior interhemispheric approach to medial frontal arteriovenous malformations: surgical technique and results. *Oper Neurosurg (Hagerstown)* 2017;13:413–420. [PubMed: 28838107]
24. Iwami K, Fujii M, Saito K. Occipital transtentorial/ falcine approach, a “cross-court” trajectory to accessing contralateral posterior thalamic lesions: case report. *J Neurosurg* 2017;127:165–170. [PubMed: 27689462]
25. Yamada K, Hayakawa T, Oku Y, Maeda Y, Ushio Y, Yoshimine T, et al. Contralateral pterional approach for carotid-ophthalmic aneurysm: usefulness of high resolution metrizamide or blood computed tomographic cisternography. *Neurosurgery* 1984;15:5–8. [PubMed: 6472593]
26. Hooper R Intracranial tumours in childhood. *Childs Brain* 1975;1:136–140. [PubMed: 1183256]
27. Yasargil MG, Jain KK, Antic J, Laciga R, Kletler G. Arteriovenous malformations of the anterior and the middle portions of the corpus callosum: microsurgical treatment. *Surg Neurol* 1976;5:67–80. [PubMed: 1257878]
28. Yasargil MG, Jain KK, Antic J, Laciga R. Arteriovenous malformations of the splenium of the corpus callosum: microsurgical treatment. *Surg Neurol* 1976;5:5–14. [PubMed: 1265626]
29. Drake CG. Cerebral arteriovenous malformations: considerations for and experience with surgical treatment in 166 cases. *Clin Neurosurg* 1979;26: 145–208. [PubMed: 544123]
30. Greenberg IM. Self-retaining retractor and handrest system for neurosurgery. *Neurosurgery* 1981;8:205–208. [PubMed: 7207785]
31. Lownie S, Wu X, Karlik S, Gelb AW. Brain retractor edema during induced hypotension: the effect of the rate of return of blood pressure. *Neurosurgery* 1990;27:901–905 [discussion: 905–906]. [PubMed: 2274131]

32. Mendelowitsch A, Langemann H, Alessandri B, Kanner A, Landolt H, Gratzl O. Microdialytic monitoring of the cortex during neurovascular surgery. *Acta Neurochir Suppl* 1996;67:48–52. [PubMed: 8870802]
33. Jadhav V, Matchett G, Hsu FP, Zhang JH. Inhibition of Src tyrosine kinase and effect on outcomes in a new in vivo model of surgically induced brain injury. *J Neurosurg* 2007;106:680–686. [PubMed: 17432722]
34. Rosenorn J, Diemer NH. The influence of intermittent versus continuous brain retractor pressure on regional cerebral blood flow and neuropathology in the rat. *Acta Neurochir (Wien)* 1988;93:13–17. [PubMed: 3414411]
35. Dagcinar A, Kaya AH, Senel A, Celik F. Sponge pieces as retractors in neurosurgical interventions. *Surg Neurol* 2007;67:493–495. [PubMed: 17445614]
36. Waring AJ, Housworth CM, Voorhies RM, Douglas JR, Walker CF, Connolly SE. A prototype retractor system designed to minimize ischemic brain retractor injury: initial observations. *Surg Neurol* 1990;34:139–143. [PubMed: 2385819]
37. Bohnstedt BN, Kulwin CG, Shah MV, Cohen-Gadol AA. Posterior interhemispheric transfalcine transprecuneus approach for microsurgical resection of peritrial lesions: indications, technique, and outcomes. *J Neurosurg* 2015;123:1045–1054. [PubMed: 25932608]
38. Oka K, Rhoton AL Jr, Barry M, Rodriguez R. Microsurgical anatomy of the superficial veins of the cerebrum. *Neurosurgery* 1985;17:711–748. [PubMed: 4069326]
39. Turner JD, Spetzler RF. Surgical approaches to arteriovenous malformations near the posterior incisura. *World Neurosurg* 2014;82:314–315. [PubMed: 24007692]
40. Filipce V, Pillai P, Makiese O, Zarzour H, Pigott M, Ammirati M. Quantitative and qualitative analysis of the working area obtained by endoscope and microscope in various approaches to the anterior communicating artery complex using computed tomography-based frameless stereotaxy: a cadaver study. *Neurosurgery* 2009;65: 1147–1152 [discussion: 1152–1143]. [PubMed: 19934974]
41. Pillai P, Baig MN, Karas CS, Ammirati M. Endoscopic image-guided transoral approach to the craniovertebral junction: an anatomic study comparing surgical exposure and surgical freedom obtained with the endoscope and the operating microscope. *Neurosurgery* 2009;64(5 suppl 2):437–442 [discussion: 442–434]. [PubMed: 19404122]
42. Sanmillan JL, Lawton MT, Rincon-Torroella J, El-Sayed IH, Zhang X, Meybodi AT, et al. Assessment of the endoscopic endonasal transclival approach for surgical clipping of anterior pontine anterior-inferior cerebellar artery aneurysms. *World Neurosurg* 2016;89:368–375. [PubMed: 26852706]

Figure 1.

(A) Arteriovenous malformation (AVM) model 1. (B) AVM model 2. *Arrowheads* indicate the points selected for assessing surgical freedom and angles of attack. (C) Ipsilateral approach. The *dotted line* defines the surgical window (SW). (D) Microscopic view for the contralateral approach. PP, posterior point; SP, superior point; A^2 , area; AP, anterior point; IP, inferior point; ACA, anterior cerebral artery; ctrl, contralateral; ipsi, ipsilateral.

Figure 2.

Illustration of surgical approach. Coronal views. **(A)** Head positioning and surgeon's point of view (POV) for the ipsilateral approach. **(B)** Head positioning and surgeon's POV for the contralateral approach. **(C and D)** Surgical circum-dissection of the AVM. The probe and *red crossed arrows* represent the measurement of the surgical freedom for the respective approaches. The *green dots* represent the points within the nidus used as critical landmarks for surgical freedom and target exposure evaluation. The inferior and superior points were used to assess the angle of attack. LPcA, left pericallosal artery; ISS, inferior sagittal sinus; RPcA, right pericallosal artery.

Figure 3.

Further steps of the interhemispheric approach. (**A** and **B**) The dura was opened and reflected toward the midline. (**C**) Bridging veins (BVs) were preserved and reflected together with the dural flap if cortical fixation allowed it. (**D**) A maximum retraction of 2 cm was applied ensuring BV integrity and exposing the interhemispheric fissure (IHF).

Figure 4.

Bar chart representing angles of attack, expressed in degrees, for the superior and inferior point in the arteriovenous malformation (AVM) model. IAIA1/2, ipsilateral anterior interhemispheric approach for AVM models 1/2; CAIA 1/2, contralateral anterior interhemispheric approach for AVM models 1/2.

Figure 5.

Bar chart representing surgical freedom relative results in percentage, being 100% the value of maximal surgical freedom: CAIA1. IAIA1/2, ipsilateral anterior interhemispheric approach for arteriovenous malformation (AVM) models 1/2; CAIA 1/2, contralateral anterior interhemispheric approach for AVM models 1/2; ACA, anterior cerebral artery.

Figure 6.

Case 1. (A and B) Preoperative angiogram of an unruptured right medial frontal arteriovenous malformation. Feeders arise from ipsilateral pericallosal and callosomarginal arteries. (C and D) Angiogram performed after the first surgery demonstrating a 5-mm remnant (*arrowhead*). (E and F) Postoperative angiogram showing not residual nidus.

Figure 7.

Case 2. (A and B) Preoperative angiogram: unruptured right medial frontal arteriovenous malformation supplied by ipsilateral pericallosal, callosomarginal and frontopolar arteries. (C and D) Postoperative angiogram demonstrating complete removal.

Table 1.

Normality Tests

Variable	Kolmogorov–Smirnov		Shapiro–Wilk	
	Value	Significance	Value	Significance
SW	0.141	0.200	0.963	0.601
AAsuperior	0.122	0.200	0.967	0.688
AAinferior	0.170	0.133	0.956	0.458
SFipsi	0.116	0.200	0.970	0.747
SFsuperior	0.118	0.200	0.974	0.842
SFcontra	0.174	0.114	0.923	0.114
SFvein	0.104	0.200	0.939	0.234

Significance values superior to 0.05 indicate that data distribution within a variable is normal.

SW, surgical window; AA, angle of attack; SF, surgical freedom; ipsi, ipsilateral anterior cerebral artery; contra, contralateral anterior cerebral artery.

Table 2.

Results of the Morphometric Analysis

Comparison of Means (Statistical Significance)							
AVM	Approach	N	Average	Increase	P Value	95% CI	
Surgical window, cm ²	I	IAIA	10	6.18	8%	0.511	-2.00, 1.03
		CAIA	10	6.66			
	II	IAIA	10	5.81	15%	0.262	-2.44, 0.71
		CAIA	10	6.68			
Target exposure, cm ²	I	IAIA	10	95.1%	4%	0.210	-11.1, 2.6
		CAIA	10	99.3%			
	II	IAIA	10	97.4%	1%	0.741	-7.4, 5.4
		CAIA	10	98.4%			
Angle of attack							
Superior	I	IAIA	10	60.1	22%	0.013	-23.1, -3.1
		CAIA	10	73.2			
	II	IAIA	10	63.6	5%	0.491	-13.3, 6.8
		CAIA	10	66.9			
Inferior	I	IAIA	10	20.6	77%	<0.001	-20.5, -11.1
		CAIA	10	36.4			
	II	IAIA	10	23.5	64%	<0.001	-18.1, -11.9
		CAIA	10	38.5			
Surgical freedom							
Superior, cm ²	I	IAIA	10	84.59	24%	0.104	-45.68, 4.69
		CAIA	10	105.09			
	II	IAIA	10	84.85	10%	0.501	-35.79, 18.32
		CAIA	10	93.59			
Ipsilateral ACA, cm ²	I	IAIA	10	12.79	108%	0.010	-21.14, -6.51
		CAIA	10	26.61			
	II	IAIA	10	16.16	89%	0.020	-26.62, -2.19
		CAIA	10				

Comparison of Means (Statistical Significance)					
AVM	Approach	N	Average	Increase	P Value
	CAIA	10	30.57		95% CI
Contralateral ACA, cm ²	I	10	14.36	92%	0.007
	IAIA	10	27.55		-22.32, -4.06
	CAIA	10	27.55		
	II	10	12.95	141%	<0.001
	IAIA	10	31.19		-27.69, -8.79
	CAIA	10	31.19		
Draining vein, cm ²	I	10	33.64	42%	0.019
	IAIA	10	47.78		-25.71, -2.57
	CAIA	10	47.78		
	II	10	27.91	66%	<0.001
	IAIA	10	46.40		-31.06, -5.91
	CAIA	10	46.40		

AVM, arteriovenous malformation; CI, confidence interval; I, AVM 1; IAIA, ipsilateral anterior interhemispheric approach; CAIA, contralateral anterior interhemispheric transfalci approach; II, AVM 2; ACA, anterior cerebral artery.