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Arteriovenous malformations of the corpus callosum: Pooled analysis and systematic review of literature

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Abstract

Background: Arteriovenous malformations (AVMs) of the corpus callosum (CC) are rare entities. We performed a systematic review of the available literature to better define the natural history, patient characteristics, and treatment options for these lesions.

Methods: A MEDLINE, Google Scholar, and The Cochrane Library search were performed for studies published through June 2015. Data from all eligible studies were used to examine epidemiology, natural history, clinical features, treatment strategies, and outcomes of patients with CC-AVMs. A systematic review and pooled analysis of the literature were performed.

Results: Our search yielded 37 reports and 230 patients. Mean age at presentation was 26.8 years (±13.12 years). AVMs were most commonly located in the splenium (43%), followed by the body (31%), and then the genu (23%) of the CC. A Spetzler-Martin grade of III was the most common (37%). One hundred eighty-seven (81.3%) patients presented with hemorrhage, 91 (40%) underwent microsurgical excision, and 87 (38%) underwent endovascular embolization. Radiosurgery was performed on 57 (25%) patients. Complete obliteration of the AVM was achieved in 102 (48.1%) patients and approximately twice as often when microsurgery was performed alone or in combination with other treatment modalities (94% vs. 49%; P < 0.001). Mean modified Rankin Scale (mRS) at presentation was 1.54 and mean mRS at last follow-up was 1.31. This difference was not statistically significant (P = 0.35).

Conclusion: We present an analysis of the pooled data in the form of a systematic review focusing on management of CC-AVMs. This review aims to provide a valuable tool to aid in decision making when dealing with this particular subtype of AVM.

Key Words: Arteriovenous malformation, corpus callosum, endovascular therapy

INTRODUCTION

Arteriovenous malformations (AVMs) of the corpus callosum (CC) are distinct clinical as well as surgical entities. They are known to cause recurrent hemorrhage more frequently as compared to more superficial, pial AVMs.[18] Optimal treatment of these AVMs is controversial not only because they tend to cause mild...
Given the paucity of literature clinical presentation, treatment rendered, and outcomes (modified Table P). We excluded articles met the above selection criteria. We included studies not published in English if they documented patient age, clinical presentation, location of AVM, treatment rendered, and outcomes (modified Yasargil’s classification). Clinical presentation, treatment strategy, obliteration rates, and outcome measures.

Definition of variables
AVM location was divided into those present in the genu, body, or splenium of the CC. Presenting symptoms were categorized as hemorrhage (i.e., subarachnoid [SAH], intraventricular, and intracerebral [ICH]), seizures, headaches, and neurological deficits. Others were classified as incidental findings. Treatment strategy was divided into microsurgical resection, endovascular embolization, radiation therapy, or a combination of two or more strategies. Obliteration rates were defined as either complete obliteration or residual AVM. Long-term outcome was defined by mRS or postoperative complications.

Statistical analysis
We used an independent two-tailed t-test (Welch generalization of the Student’s t-test, Microsoft Excel, 2013, Redmond, WA, USA) to compare preoperative and postoperative mRSs. Chi-square test was utilized to compare the difference in AVM obliteration rates achieved by various treatment modalities. P value of 0.05 was considered statistically significant.

RESULTS
Eligibility criteria described in the methods section were met by 37 articles, with a total of 230 patients [Table 1]. Individual patient data could be obtained from 31 reports. All reports were retrospective observational cohorts, case reports, and case series. No prospective cohorts or randomized studies were found.

The mean patient age at presentation was 26.82 years (±13.12 years; range 2–61 years; median 25 years) with a slight male (55%) preponderance. CC-AVMs were most commonly located in the splenium (99 patients; 45%), followed by the body (72 patients; 31%), and then the genu (54 patients; 23%). Two or more areas of CC were
Table 1: Studies reporting patients with corpus callosum arteriovenous malformations

| Author and year       | Number of patients | Mean age (years) | Male: female | Presentation | Location of AVM | S-M grade | Treatment | Obliteration status* | Mean initial mRS | Mean follow-up mRS | Complications |
|-----------------------|--------------------|------------------|--------------|--------------|-----------------|-----------|-----------|----------------------|-----------------|-------------------|---------------|
| Akimoto 2003          | 1                  | 27               | 0:1          | HA, numbness | Splenium, body  | IV        | Surgery   | Complete             | 1               | 0                 | None          |
| Andreussi 1978        | 1                  | 13               | 0:1          | HA, LOC      | Genu            | II        | Surgery   | Complete             | 5               | 1                 | None          |
| Baiz 1964             | 1                  | 16               | 0:1          | HA, blurred vision | Splenium, body  | IV        | Surgery   | Complete             | 4               | 0                 | Foot weakness |
| Bartal 1970           | 1                  | 7                | 1:0          | Hemiplegia   | Genu, body      | III       | Surgery   | Complete             | 5               | 3                 | None          |
| Bendavid 2004         | 1                  | 2                | 0:1          | HA           | Genu            | III       | Surgery   | Complete             | 1               | 0                 | None          |
| Bukliina 2002         | 36                 | 25               | NA           | Hemorrhage   | Genu: 9         | NA        | Surgery: 29 | Observed: 7          | NA              | NA                | NA            |
| Castro-Caldas 1983    | 1                  | 30               | 0:1          | HA           | Body, splenium  | IV        | Surgery   | Complete             | 1               | 0                 | None          |
| Cone 1979             | 3                  | 25               | 2:1          | HA, seizures, IVH | Genu: 1         | II: 1     | Surgery: 1 | Observed: 2          | 0               | 0                 | None          |
| Da Pian 1980          | 2                  | 25.5             | 1:1          | SAH          | Body: 1         | II: 1     | Surgery   | Complete             | 4.5             | 2                 | None          |
| Dikel et al., 2001    | 1                  | 6                | 1:0          | HA           | Holocallosal    | IV        | Surgery + embolization + XRT | NA             | 1                 | None          |
| Ganapathy et al., 2003| 1                  | 39               | 1:0          | HA           | Holocallosal    | V         | XRT       | Complete             | 1               | 0                 | None          |
| Garza-Mercado et al., 1987| 1    | 15               | 0:1          | SAH          | Holocallosal    | IV        | Surgery   | NA                   | 4               | 6                 | Death         |
| Guidetti 1982         | 15                 | 35               | 10:5         | SAH: 14 Deficit: 1 | Body: 3         | NA        | Surgery: 11 | Observed: 4          | 1.87            | 2.87              | Contd..        |
| Herzig 2000           | 1                  | 45               | 0:1          | SAH          | Splenium        | III       | XRT       | Complete             | 0               | 0                 | None          |
| Houtteville 1989      | 1                  | 18               | 0:1          | SAH          | Body            | II        | XRT       | NA                   | 0               | 1                 | None          |
| Juhasz 1978           | 2                  | 14               | 0:2          | SAH          | Splenium        | III       | Surgery   | Complete             | 0               | 1                 | None          |
| Kohmura 1990          | 1                  | 23               | 1:0          | Incidental   | Splenium        | III       | Surgery   | Incomplete            | 0               | 1                 | None          |
| Kosary 1978           | 3                  | 20               | 2:1          | HA           | Splenium        | II        | Surgery: 3 | Complete: 2          | 2               | 3                 | Hemianopsia: 1 |
| Koyanagi 1985         | 1                  | NA               | 1:0          | NA           | Body            | III       | Embolization + surgery | Complete | NA                | NA            |
| Kunc 1974             | 8                  | NA               | NA           | SAH          | Genu: 4 Body: 1 | NA        | Surgery: 4 | NA                   | NA              | Excellent          | None          |
| Lobato 2002           | 1                  | 58               | 0:1          | SAH          | Body            | IV        | Embolization + surgery | Complete | 0                 | Memory deficit |
| Machado 1984          | 1                  | 25               | 0:1          | SAH          | Body and splenium | IV        | Surgery   | Complete             | 0               | 1                 | None          |

Contd..
involved in 13 patients (6%) whereas the entire CC was involved in 21 (9%). Spetzler-Martin grade was reported or could be calculated for 135 patients. The most common Spetzler-Martin grade was 3 (51 patients; 37%) followed by 2 (38 patients; 28%).

Overall, analysis of 230 patients showed that 187 (81.3%) presented with hemorrhage, 5 with focal neurological deficit, 10 with seizures without hemorrhage, and 18 with headaches as the primary symptom. Ninety-one (40%) patients underwent microsurgical resection of the AVM. Endovascular embolization was performed either as a preoperative adjunct or as a stand-alone treatment modality in 87 (38%) patients. RS was administered to 57 (25%) patients while two or more treatment modalities were used in 21 patients (9%).

Table 1: Contd...

| Author and year | Number of patients | Mean age (years) | Male: female | Presentation | Location of AVM | S-M grade | Treatment | Obliteration status | Complications |
|-----------------|--------------------|------------------|--------------|--------------|-----------------|-----------|-----------|-------------------|---------------|
| Maruyama 2005[29]| 32                 | 25               | 15:17        | SAH: 28; Other: 4 | Genu: 5; Body: 9; Splenium: 19 | I: 2; II: 8; III: 17; IV: 4; V: 1 | XRT | Complete: 21; Incomplete: 11 | NA; NA | Dysarthria: 1 |
| McDonald 2001[30]| 1                  | 47               | 1:0          | Memory impairment | Splenium | III | Embolization + XRT | NA | 0 | Memory impairment |
| Milhorat 1970[31]| 1                  | 16               | 1:0          | SAH | Body | IV | Surgery | Complete | 0 | None |
| Mohanty 2011[32]| 1                  | 13               | 1:0          | SAH | Body | II | XRT | Complete | 0 | None |
| Orozco 2013[34]| 2                  | 48.5             | 1:1          | SAH and seizure | Body | III and IV | Embolization: 1 + surgery: 1 | Complete in 1 patient undergoing surgery; Incomplete: 1 | 3 | 2.5 | Hemiparesis |
| Picard 1996[37]| 43                 | 30               | 25:18 | SAH: 36; Seizures: 4; HA: 2; Ataxia: 1 | Genu: 11; Body: 6; Splenium: 20; Holocallousal: 9 | NA | Embolization: 43; XRT: 9 | Complete: 8; Incomplete: 1 | NA | NA | Death: 1 | Neuro deficit |
| Robert 2015[39]| 38                 | 31               | 17:21 | Hemorrhage: 30; Incidental: 1; Seizures: 4; Neuro deficit: 3 | Genu: 14; Body: 19; Holocallousal: 5 | I: 2; II: 20; III: 9; IV: 6; V: 1 | XRT: 9 | Complete: 22; Incomplete: 35 | NA | 1.05 | None |
| Sell 1997[40]| 1                  | 20               | 0:1          | SAH | Fornix and splenium | III | Surgery | Incomplete | 5 | 2 | Memory deficits; Seizures: 1 |
| Shi 1987[41]| 5                  | 25               | 4:1          | SAH | Body | II: 1; III: 4 | Surgery | Complete | 2 | 0.8 |
| Shimizu 2001[22]| 1                  | 50               | 1:0          | Incidental | Body | III | XRT + embolization | Complete | 1 | 0 | None |
| Uchino 1989[47]| 1                  | 16               | 0:1          | SAH | Genu and body | V | XRT | Incomplete | 2 | 1 | None |
| Valenstein 1957[48]| 1              | 39               | 1:0          | SAH | Splenium | II | Surgery | Complete | 2 | 2 | Memory deficits |
| Wang 2001[50]| 1                  | 51               | 1:0          | SAH | Genu and body | V | Surgery | Complete | 5 | 4 | Hemiparesis |
| Yasargil 1976[51]| 8                  | 23.6             | 5:3          | SAH | Genu: 5; Body: 6; Splenium: 10 | III: 1; IV: 4; V: 3 | Surgery | Complete | 1.25 | 1.1 | Hemiparesis: 1 |
| Yasargil 1976[51]| 10                 | 28.2             | 8:2          | SAH: 7; HA: 3 | Splenium: 10; Holocallousal: 1 | III: 6; IV: 2; V: 2 | Surgery | Complete: 5; NA: 5 | 0.6 | 0.7 | Hemianopsia: 3; Seizures: 2 |

*Angiographic obliteration in patients undergoing any treatment modality. NA: Data not available, LOC: Loss of consciousness, HA: Headache, IVH: Intraventricular hemorrhage, SAH: Subarachnoid hemorrhage, ICH: Intracranial hemorrhage, XRT: Radiation therapy, S-M: Spetzler-Martin, AVM: Arteriovenous malformation, NOS: Not otherwise specified
were used in combination in 23 (10%). Cumulatively, 212 (92.1%) patients received treatment whereas 18 (7.8%) were managed conservatively. Complete obliteration of the AVM was achieved in 102 (48.1%) patients. This was accomplished by microsurgery in 44 (43.1%) patients, embolization in 20 (19.6%), RS in 24 (23.5%), and combination therapy in 14 (13.7%).

Residual AVM was observed in 60 (28.3%) patients. Half of these patients underwent stand-alone embolization (30 patients; 50%), 12 (20%) RS alone, and 15 (25%) received combination therapy of embolization and RS. Of those who underwent surgical resection, only 3 (5%) patients had a residual nidus. Stand-alone surgical resection or in combination with other treatment modalities resulted in complete obliteration in 47 of 50 (94%) patients whereas only 55 (49%) of 112 who underwent embolization alone, RS alone, or combination therapy with embolization and RS achieved complete obliteration. This difference was found to be statistically significant ($P < 0.001$). Thirty-two patients encountered complications in the immediate posttreatment period; however, only 26 patients were left with long-lasting adverse effects from treatment. Three deaths were noted in the literature; 2 occurred posttreatment, and 1 patient died after managed conservatively. Mean mRS at presentation was 1.54 and mean mRS at last follow-up was 1.31. The difference between the initial and final mRS was not statistically significant ($P = 0.35$) [Table 2].

### DISCUSSION

#### Epidemiology and natural history

CC-AVMs are relatively rare. The literature is only populated with case series and case reports; hence, the natural history of these lesions remains largely unknown. The prevalence of CC-AVMs ranges from 1.1% to 3% in population-based studies\(^\text{41,42}\) and from 6.7% to 14.8% in hospital-based cohorts.\(^\text{1,33,40}\) Patients with CC-AVMs present at a younger age as compared to patients with superficial AVMs. In a report by Buklina, the mean age of patients at presentation was 25 years\(^\text{9}\) whereas it was 35 years in a series reported by Guidetti and Spallone.\(^\text{18}\) CC-AVMs comprise 8–9% of all intracranial AVMs.\(^\text{18}\)

Since CC-AVMs are considered deep-seated lesions, the risk of hemorrhage at presentation and subsequent rehemorrhage is considered to be higher than superficial lesions, mostly by virtue of their location and deep venous drainage.\(^\text{44,45,49}\) Our literature search yielded 37 reports describing 230 patients with CC-AVMs. Most patients harboring CC-AVMs present with ICH. Examining individual reports consisting of multiple patients revealed that 70–100% of patients present with ICH or SAH. Overall, 187 (81.3%) of 230 patients presented with hemorrhage, 10 (4%) presented with seizures without hemorrhage, and 18 (7.8%) presented with headache as the primary symptom.

#### Anatomical considerations

CC-AVMs are generally supplied by the branches of the anterior cerebral artery and the posterior cerebral artery (PCA) with minor contributions from the middle cerebral artery. A recent study indicated that 27 (59%) of the 46 nidi studied were supplied by both anterior and posterior circulations and 30 (65%) of 46 nidi were fed by bilateral pericallosal arteries.\(^\text{17}\) Venous drainage generally occurs through the superior and inferior sagittal sinuses and the galenic system.

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**Table 2: Patient characteristics with corpus callosum arteriovenous malformations**

| Patient characteristics                  | n        |
|------------------------------------------|----------|
| Number of reports                        | 37       |
| Eligible patients                        | 230      |
| Mean age (±SD) years                     | 26.8 (±13.12) |
| Gender ($n=185$) (%)                     |          |
| Males                                    | 101 (54.5) |
| Females                                  | 84 (45.4)  |
| Presentation (%)                         |          |
| Hemorrhage                               | 187 (81.3) |
| Seizures                                 | 10 (4)    |
| Headache                                 | 18 (7.8)  |
| Others                                   | 15 (6.5)  |
| Location (%)                             |          |
| Genu                                     | 54 (23.4) |
| Body                                     | 72 (31.3) |
| Sphenium                                 | 99 (43)   |
| >Two locations                           | 13 (5)    |
| Holocallosal                             | 21 (9.1)  |
| S-M grade ($n=135$) (%)                  |          |
| I                                        | 4 (2.9)   |
| II                                       | 38 (28)   |
| III                                      | 51 (37.7) |
| IV                                       | 27 (20)   |
| V                                        | 15 (11.1) |
| Treatment (%)                            |          |
| Surgery                                  | 91 (39.5) |
| Embolization                             | 87 (37.8) |
| Radiation treatment                      | 57 (24.7) |
| Combination therapy                      | 23 (10)   |
| Complications (%)                        |          |
| Immediate                                | 32 (13.9) |
| Long-term                                | 26 (11.3) |
| Death                                    | 3 (1.3)   |
| Outcomes (mean mRS)                      |          |
| At presentation                          | 1.54      |
| At follow-up                             | 1.31      |

S-M: Spetzler-Martin, SD: Standard deviation
Preoperative neuropsychological testing

Of the 18 patients, 15 had presented with headaches and altered mental status. Fifteen of these underwent a complex clinical-neuropsychological study in just a few patients. Buklina et al. undertook a complex clinical-neuropsychological study in 36 patients who underwent surgical treatment of ruptured CC-AVMs. Preoperative neuropsychological testing performed on the same patient reveals an extensive arteriovenous malformation involving the genu, rostrum, and body of the corpus callosum. Intranidal aneurysm is also appreciated (black arrow). Early venous drainage is seen via galenic system (white arrow). Lateral projection of internal carotid artery injection reveals a large arteriovenous malformation involving the genu, rostrum, and body of the corpus callosum. Intranidal aneurysm is also appreciated (black arrow). Early venous drainage is seen via galenic system (white arrow). Lateral projection of vertebral artery injection reveals filling of the splenial component of the arteriovenous malformation nidus not seen with internal carotid artery injection (white arrow).

Anatomically, CC-AVMs can be divided into four main groups as described by Yasargil et al. The first group includes those lesions that involve the genu and/or anterior portion of the CC. Pericallosal arteries are the typical feeders for this group of AVMs, with occasional contributions from the callosomarginal and anterior choroidal arteries. Venous drainage occurs mostly through the inferior sagittal sinus via the callosal and septal veins or the vein of Galen via internal cerebral veins. The second group of CC-AVMs consists of lesions involving the trunk or the splenium of the CC. These lesions are usually fed by either unilateral or bilateral pericallosal arteries. Venous drainage occurs via the vein of Galen through the transcallosal vein; however, the inferior sagittal sinus may be involved as well. The third group consists of AVMs involving the posterior third of the body or splenium of the CC. These, too, are fed mainly by the pericallosal arteries and branches of the PCA including posterior pericallosal and posterior choroidal arteries. Venous drainage is mainly through the internal cerebral veins and vein of Galen. The fourth group consists of holocalllosal AVMs, which can have variable feeders and drainage patterns. An example of a holocalllosal AVM is demonstrated in Figure 1.

Picard et al. further divided the AVM nidus into three types such as (1) the “compact” nidus, which is well demarcated and located within the CC; (2) an “extensive” nidus involving the cingulate gyrus or septum pellucidum in addition to the CC; and (3) a “diffuse” nidus which is ill-defined and involves various cortical, subcortical, and intraventricular regions.

Our analysis reveals that the most common location for CC-AVMs is the splenium. Approximately 10% of all CC-AVMs involve the white matter structure in its entirety, and these are the most difficult to treat.

Treatment

Multimodal treatment of complex AVMs is advocated. Microsurgical resections aided by endovascular embolization and stereotactic RS are the cornerstones of therapy for any AVM. Although advances in microsurgery have made complete resection of these “inoperable” lesions possible, the cure comes with a considerable risk of developing new neurological deficits. Endovascular embolization rarely achieves complete obliteration of the AVM but can significantly aid in occluding feeders that are difficult to access early in surgery. Utilization of RS for deep-seated AVMs with nidi measuring <3 cm3 in volume has increased significantly over the last two decades with encouraging results. A more detailed discussion of these treatment modalities is as follows.

Surgical resection

Historically, surgical resection of CC-AVMs has been fraught with significant morbidity. However, with advanced microsurgical techniques and widespread availability of surgical adjuncts such as preoperative endovascular embolization and radio surgical downgrading, better results are seen in the more recent literature. One of the earliest series of surgical resection of CC-AVMs was published by Yasargil et al., in 1976. Eighteen patients were treated with microsurgical resection without preoperative embolization or radiotherapy. Of the 18 patients, 15 had presented with hemorrhage and all patients belonged to a younger age group. A unilateral frontal parasagittal craniotomy and interhemispheric approach were employed in all cases for AVMs located in the anterior and middle of the CC whereas a paramedian parietal or parietooccipital craniotomy in sitting position was performed for most splenial AVMs. From a technical standpoint, the authors considered splenial AVMs to be more challenging since most of these were within the substance of the splenium and required splitting the splenium along the direction of its fibers. No operative mortality or major neurological morbidity was encountered. Hemianopsia and new onset seizures were the only postoperative complications and reported in just a few patients. Buklina et al. undertook a complex clinical-neuropsychological study in 36 patients who underwent surgical treatment of ruptured CC-AVMs.
Our analysis of the literature revealed that fifty patients underwent standalone endovascular embolization of the AVM and cure was achieved in only 20 (40%), similar to the results noted by Picard et al. Only four patients underwent presurgical embolization of their AVMs, of which 3 (75%) were completely excised. Similarly, 26 patients underwent endovascular embolization of the AVM before radiation was delivered, but the AVM was completely occluded in only 11 (42.3%). Therefore, the authors believe that although endovascular intervention is extremely helpful in cases of large AVMs with multiple feeders or AVMs with deep or inaccessible feeders, complete obliteration is rarely achieved and microsurgery or RS must supplement embolization to achieve definitive cure.

**Radiosurgery**

RS is increasingly employed for treatment of small (<3 cm³) as well as some medium- (3–6 cm³) and large-size (>6 cm³) AVMs located in deep cerebral tissue. RS is an attractive choice due to its noninvasive nature, minimal risk for acute complications, and shorter recovery time for the patients. However, cure is not immediate and can take 2–3 years for the effects of radiation to result in thrombosis of the AVM. Although smaller AVMs (<3 cm³) are ideal candidates for RS, several reports have confirmed lower obliteration rate in larger AVMs.[22,35,36,46,53] Staged RS as well as prior embolization to aid in the reduction of radio surgical treatment volume has been utilized in the management of large AVMs not amenable to surgery.[1,14] Obliteration rate varies based on the AVM volume. Obliteration rate in AVMs with volumes between 10 and 15 cm³ has been shown to be approximately 77%, compared to 25% for those with a volume >15 cm³.[25] Larger AVMs also require a longer time for obliteration to occur.[15] User-friendly tools are rapidly becoming available that can guide clinicians on likelihood of AVM obliteration after RS as well as treatment-related morbidity. The RS-based grading system and the Virginia RS AVM scale were developed recently and consider AVM volume and location, patient age, and history of hemorrhage when determining a score.[10,43]
There is a paucity of available literature on CC-AVMs. The appropriate treatment strategy for these rare lesions remains controversial. Through this systematic review of literature and analysis of pooled data encompassing almost half a century, the authors have attempted to provide a tool that will assist healthcare providers to formulate an individualized treatment plan for these patients. Although microsurgical resection offers the most definitive treatment of these lesions, improved outcomes have been observed when microsurgery is supplemented with advances in RS and endovascular therapy. However, the decision to treat a patient with CC-AVM should weigh the natural history of these lesions against potential neurological and neuropsychological morbidity that may follow treatment.

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**Conflicts of interest**

There are no conflicts of interest.

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CONCLUSIONS
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