

## Cerebral Arteriovenous Malformation, Cerebral Cavernoma, and Cerebral Aneurysm: Management and Outcome During Pregnancy and Puerperium with Focus on Neurosurgical Side

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### Abstract

**Background:** Cerebral cavernoma, cerebral arteriovenous malformation, and incidental cerebral aneurysm are rare but challenging conditions during pregnancy and puerperium. The primary diagnostic and identification techniques used to determine and evaluate these conditions in terms of morphology, location, and presentation are brain CT scan, MRI, and DSA. With ideal treatment of these conditions still unclear, neurosurgery is the most commonly preferred intervention technique.

**Objective:** The aim of extracting data from the published studies to identify the most common neurosurgical procedures used for successful management and outcomes of CCM, cerebral AVM, and incidental cerebral aneurysms during pregnancy and puerperium.

**Methods:** It was performed as comprehensive search into PubMed, Google Scholar, Science Direct, PubMed Central, Medline, and Research Gate databases for studies published between January 2000 to 20th January 2022. The search terms were "Cerebral cavernoma" or "cavernous cerebral malformation" or "CCM" or "cavernoma in pregnancy and puerperium"; "cerebral arteriovenous malformations" or "arteriovenous malformations" or "AVM"; "cerebral incidental aneurysm" or "intracranial aneurysm" or "incidental aneurysm" or "cerebral aneurysm in pregnancy"; "intracranial vascular malformations"; "neurosurgical treatments in pregnancy and puerperium"; "management of vascular malformation."

**Results:** A total of 11 studies met our inclusion criteria and were included for the review. From the studies reviewed, the significant neurosurgical intervention performed among the participants were craniotomy,

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surgical resection, endovascular techniques, surgical clipping, surgical evacuation, embolization, and dissection.

**Conclusion:** It concluded that effective management and treatment must be done independently and specific to each case presented. The multidisciplinary treatment option is fundamental for successful management outcomes during pregnancy and puerperium.

**Keywords:** Cerebral cavernoma; Pregnancy; Puerperium; Endovascular techniques; Treatment.

## Abbreviations

CCM:Cavernous cerebral malformation; AVM:Arteriovenous malformation; C-AVM:Cerebral arteriovenous malformation; ICH:Intracranial hemorrhage; CS:Cesarean surgery.

## Introduction

Different scientific and neurological researchers have reviewed cerebral complications occurring in pregnancy and puerperium due to their severity and diversity in identification. Brain vascular malformations are the leading causes of intracranial hemorrhages during pregnancy and postpartum and are among the top three leading causes of indirect maternal deaths [1,2]. They form rare but high-risk pregnancy complications and puerperium associated with intracranial hemorrhage, both intracerebral and subarachnoid hemorrhagic events. Intracranial hemorrhages are influenced by conditions such as arterial dissection, pituitary apoplexy, eclampsia, intracranial venous thrombosis, and coagulopathy [1,3]. The increasing abilities of brain imaging and the application of advanced technology significantly identify the various categories and incidents of intracranial vascular malformations leading to management dilemmas and complications. The most commonly identified intracranial vascular malformations during pregnancy and puerperium are cerebral cavernoma, cerebral arteriovenous malformations,

developmental venous anomalies, and incidental cerebral aneurysm. Most research conducted identifies neurosurgical interventions as the most preferred solutions [1,3-5], yet every vascular malformation presents itself in unique nature and differ to every patient.

The development of intracranial hemorrhage (ICH) detected during pregnancy categorizes it as an urgent neurosurgical condition beyond obstetric treatment and consideration. Although similar interventions are applied to expectant and non-expectant women [2,6] practical decision-making involves vast knowledge and experience on the pathophysiology of the condition and physiology of the pregnancy. ICH is the primary cause of stroke-associated pregnancies due to the influence of hemostatic changes during pregnancy, with aneurysmal subarachnoid hemorrhage being the most predominant among expectant women [7]. The ICH is mainly categorized into intracerebral, extradural, subarachnoid, and subdural based on their triggers [2]. Intracerebral hemorrhage occurs in the various condition such as arteriovenous malformation [8], preeclampsia and

eclampsia, cerebral venous thrombosis, neoplasia, Moya-Moya disease, and cavernous malformations [9].

Cerebral cavernoma malformations (CCM) involve large abnormally viscous vascular channels found between the sinusoidal vessel except for brain parenchyma. They are also referred to as cavernous hemangiomas, cavernous angiomas, and cavernoma and can be clinically identified through presentations of symptoms and natural history [5]. The CCM mainly affects the central nervous system in the brain stem, and it appears several centimeters in size. Different literature indicates that CCM occurs in young children and adults and may spontaneously regress during a lifetime [10]. Effective intervention and diagnosis of this condition require adequate knowledge and understanding of its natural history, which is fundamental for successful management. CCM's pathogenesis is linked to three homologically distinct genes, CCM<sub>1</sub>, CCM<sub>2</sub>, and CCM<sub>3</sub>, which cause high genetic penetration due to de novo mutations or environmental exposure. The genes significantly interact within the system as cellular machinery influencing angiogenesis and intercellular communications [11]. It is differentiated from other cerebral vascular malformations because of the absence of intervening parenchyma and lack of direct arteriovenous communication. According to [12], the clinical presentations of CCM involves focal neurologic deficit, impaired consciousness, acute headache in isolation, and seizures connected to acute or subacute hemorrhage identified through surgical, radiologic, pathologic, and cerebrospinal

fluid determinations. The ideal treatment for CCM remains debatable due to clinical presentation, available interventions, natural history and outcomes, and pathophysiological characteristics.

Cerebral arteriovenous malformation (C-AVM) are abnormal vascular networks within the brain arteries and veins that lack an actual capillary bed and intervening network of vessels causing arteriovenous shunting. The transition between the arteries and veins may occur through nidus or directed without intervening connections. C-AVM consists of uncommon congenital vascular lesions clinically presenting in the form of headache, limb dysfunction, vertigo, seizures, hallucinations, confusion, aphasia, and muscle weakness [13]. Its symptoms in pregnancy are mistakenly differentially diagnosed as cerebral venous thrombosis, migraine, eclampsia, and preeclampsia; hence, accurate diagnosis is essential for the initiation of appropriate therapy. The hormonal changes, notably progesterone and estrogen, critically influence cerebral blood flow during pregnancy caused by their vasodilatory effects [8]. Other literature has connected the C-AVM hemorrhage to associated aneurysms, increasing age, deep venous drainage, high artery feeding pressure, deep brain location, and small nidus size, which significantly forms independent predictors [4,14]. Upon diagnosis by intra-arterial digital subtraction angiography, the fundamental decision to proceed with operation or surgical procedure among pregnant women is debatable, following the risks of rupture, rebleeding, and neurological indications. Even though techniques like

endovascular embolism, microsurgery, and radiosurgery are considered the major treatment interventions, there are ongoing investigations and debates on the appropriate global grading system for selecting microsurgical resection of C-AVM [7]. Therefore, management and treatment options differ among pregnant women based on the acute presentation of the C-AVM and gestation period. The incidental cerebral aneurysm is presented in different forms as localized malformations on a significant arterial wall on the Circle of Willis. Morphologically, the intracranial aneurysm is categorized into a fusiform aneurysm, dissecting aneurysm, myotic aneurysm, and saccular aneurysm [1]. The unruptured cerebral incidental aneurysm is commonly asymptomatic, yet in rare cases, they influence the formation of cranial neuropathies as a consequence of external compression. The uncertainty of the long-term risks attributed to the incidence of hemorrhage of the unruptured intracranial aneurysm; resulted in the formulation of principal risk factors such as aneurysm location, its increase in size, female gender, advancing age, and Japanese or Finnish origin, as part of the natural history of the condition [2].

The significant challenges experienced in its differential diagnosis from subarachnoid hemorrhage, intracranial hemorrhage and its rare nature during pregnancy limit the development of reliable data on the incidence of cerebral aneurysm and its outcomes. The therapeutic interventions aim to provide better short-term and long-term results by preventing rebleeding and enabling

evacuation of the aneurysm [2]. Thus, [15] argues that neurosurgical clippings and endovascular coiling are desirable outcomes with the same management for expectant and non-expectant women. The application of sophisticated technologies in diagnostic health has significantly increased the appropriate detection of cerebral vascular malformations in neurobiology. With the increasing frequencies of detections and information, a significant dilemma lies in the effective management mechanism designed for every abnormality, particularly during pregnancies and puerperium, to meet the desired neurosurgical outcomes [10].

The risk complexities of these conditions, pathophysiological presentations, and the physiological changes during pregnancy and puerperium have over decades created dilemmas debated among researchers, neurosurgeons, obstetricians, expectant mothers, and neurologists on the ideal treatment methods for intracranial hemorrhages [16]. Enhanced challenges and risks of intracranial vascular malformation require a multidisciplinary team's collaborative intervention to avoid severe outcomes [6]. Therefore, this article presents a systematic review of available literature on the management and outcomes of cerebral cavernoma, cerebral arteriovenous malformation, and incidental cerebral aneurysm during pregnancy and puerperium, with a critical focus on neurosurgical interventions.

## Methodology

This systematic review focused on the neurosurgical interventions that significantly

enhance the management and outcomes of the identified types of intracranial vascular malformations during pregnancy and puerperium. Therefore, literature data reviewed and included in this review were identified with central terminologies of cerebral cavernoma, cerebral arteriovenous malformation, incidental cerebral aneurysm, intracranial vascular malformation, cerebrovascular disease abnormalities, and intracranial hemorrhage associated with pregnancy and puerperium.

### **Development of the protocol**

A protocol was created and systematically designed to address the study objectives and aims. The protocol captured the main review methods: search strategy, data abstraction, data synthesis, inclusion criteria, quality assessment, and screening methods. The reports on this systematic review are according to the Preferred Reporting Items for Systematic Reviews and Meta Analyses (PRISMA).

### **Eligibility**

#### **Inclusion and exclusion criteria for review studies**

Studies identified with cases of either of the three intracranial vascular malformations or cerebrovascular abnormalities (cerebral cavernoma, cerebral arteriovenous malformation, and cerebral intracranial aneurysm) considered for inclusion.

The identified studies with interest conditions were further scrutinized for information on either pregnancy, puerperium, or neurosurgical management.

Studies that did not meet these criteria and systematic review studies and those published before January 2000 were excluded from the study.

### **Search strategy**

This systematic review adopted the fundamental recommendations of PRISMA. Systematic literature analysis and search were done through PubMed, Google Scholar, Science Direct, PubMed Central, Medline, and Research Gates, identifying a database of studies on cerebral cavernoma, cerebral arteriovenous malformation, and cerebral incidental aneurysm's management and outcome during pregnancy and puerperium. The search included studies from 1st January 2000 until 20th January 2022 to enhance the possibilities of a large sample size and more recent publications that have not been included in other reviews. The keywords used in the search strategy include, "Cerebral cavernoma" or "cerebral cavernoma malformation" or "CCM" or "cavernous hemangiomas" or "cavernous angiomas" or "cavernoma in pregnancy and puerperium"; "cerebral arteriovenous malformations" or "arteriovenous malformations" or "AVM" or "cAVM" "congenital vascular lesions" or "abnormal vascular networks"; "cerebral incidental aneurysm" or "intracranial aneurysm" or "intracranial hemorrhage" or "subarachnoid hemorrhage" or "incidental aneurysm" or "cerebral aneurysm in pregnancy"; "cerebrovascular abnormalities"; "intracranial vascular malformations"; "neurosurgical treatments in pregnancy and puerperium"; "management of vascular malformation"; "outcomes of vascular malformation".

## Study selection

The selection criteria involved screening the title and abstract and full-text analysis to identify the required articles for the systematic review and inclusion criteria. Two independent reviewers critically reviewed the studies selected for inclusion by fundamentally considering the inclusion and exclusion criteria. First, the titles with keywords were considered, then followed by abstract screening, and those with relevant information were considered for full-text. Differences and discrepancies between the two reviewers on selection and inclusion of any article were succinctly discussed until affirmation by consensus. All academic material from clinical trials, case reports, and cohort studies that met inclusion criteria included. Case study reports, articles, books, and forum summaries eligible for the study and with at least one pregnant or puerperium patient having cerebral conditions of interest considered.

## Data collection

Data collection was done by two reviewers working independently using a specifically designed excel sheet with all aspects of information on the selected studies' neurosurgical methods, management, and outcomes. The application of Cochrane recommendations enabled the reviewers to design standardized pre-piloted data extraction forms used for data collection from the eligible studies and signed with the reviewers' initials [17].

The extracted data from the two reviewers were compressed into a single form and

crosschecked for accuracy, reliability, variability, and validity of the obtained data. the selected studies were considered for systematic review.

## Assessment of risk of bias of the included studies

The two reviewers independently assessed the risk of bias and performed data extractions using a designed protocol according to the Cochrane Handbook [17]. The risk of bias assessment utilized six significant aspects: conflict of interest bias, selection bias, performance bias, reporting bias, attrition bias, and detection bias, further categorized based on their severity and influences towards the study outcomes, hence high-risk, low risk, and unclear. The unclear risk involved those studies with one domain unfulfilled; low risk indicated all the identified assessment domains, and high risk had two or more missing domains designed for assessment.

## Result synthesis

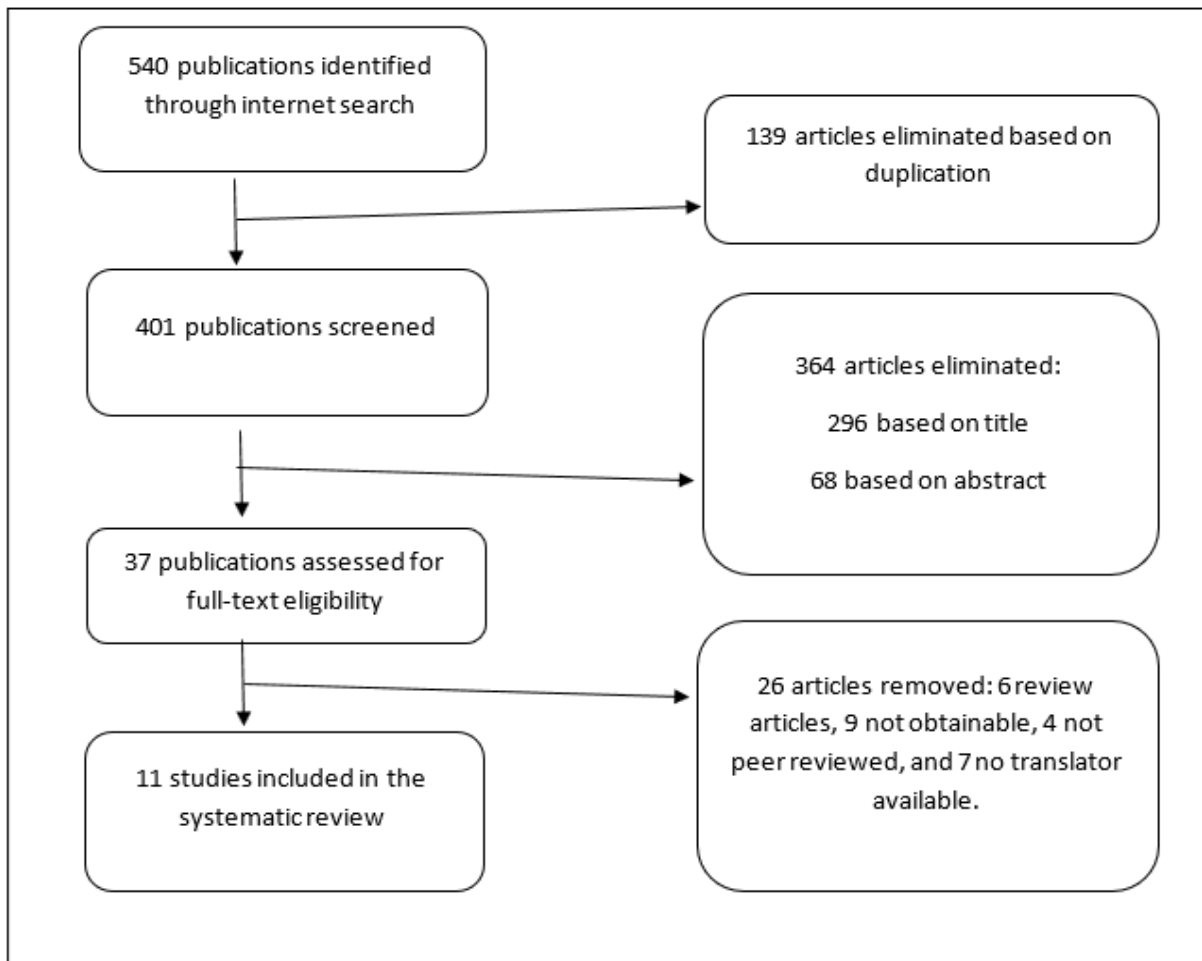
The findings from the selected studies were pooled together based on the Cochrane Handbook for Systematic Reviews of Interventions [17]. The fundamental criteria that supported the inclusion for systematic reviews were based on management outcomes, neurological interventions, pregnancy or puerperium, cerebral vascular malformations, study conditions, and homogeneity of the participants. The diagnostic techniques used to identify the interest requirements and determine deferential diagnosis were considered with the available treatment option. In cases of

significant heterogeneity of the initial study outcomes, comprehensive illustrations and inferences were made.

## Results

The internet search yielded 540 publications, articles, books and journals. Screening by duplication left 401 studies. Further, screening by the relevance of the title and abstract information to the review objectives and incidents of systematic reviews left 37 studies. Finally, after the screening, individual studies were further subjected to full-text reviews,

which left 11 articles were considered to contain viable and accurate data (Figure 1). The application of PRISMA guidelines for inclusion and exclusion criteria is indicated in Figure 1. It is important to note that some of the studies included in the systematic review did not provide sufficient information on the subject. However, basic information significantly developed the context for the subject matter, which is included in the reference material. Therefore, the summary of the findings of the individual studies included in the study is captured in Table 1.



**Figure 1:** PRIMSA flow chart.

Serial No	Author	Year	Study Design	Study Population	Outcome
1	Mesbahi T, et al.	2021	Case report	1	The study found that cerebral cavernoma indicates hemorrhagic potential with 0.5% prevalence in the general population. With magnetic resonance imaging (MRI) development, much is currently understood concerning its pathology type of vascular malformation. The study further indicated no established or mandated management intervention for cerebral cavernoma in pregnancy. Thus, surgical management depends on the symptomology, gestational age, and fetal and maternal risk-benefit mechanism.
2	Liu XJ, et al.	2014	Case Crossover Study	979	The study established no increased risk or direct association of AVM rupture among pregnant and puerperium women within the child-bearing age (18-45 years). Based on many participants, most of the intracranial hemorrhages were presented in the second and third trimesters due to significant changes in the vessel wall, hemodynamic parameters, and coagulative functions. It indicated that treatment and management of AVM rupture are complex, different, and controversial but critically depends on timely and accurate diagnosis with digital subtraction angiography (DSA) and computed tomography (CT) scan. The study indicates that although surgical resection and evacuation are not the first choices for treating AVM rupture, they remain fundamental for grade I and IV AVM, where brain herniation is evident. The study concluded that ruptured AVM during pregnancy and puerperium is a challenging condition that requires interprofessional management.
3	Martinez-Galiano JM, et al.	2019	Cross-sectional Study	3324	The study identified that cesarean section (CS) is associated with risk factors not limited to post-traumatic stress disorder, anxiety, depression, headache, back pain, the maternal feeling of sadness, and wound infection during the puerperium period. While instrumental delivery was associated with constipation, headache, psychological alteration, hemorrhoids, wound infection, and perineal pain during puerperium. This indicates that surgical interventions during pregnancy and puerperium enhance the patient's real risks, contributing to the increased maternal morbidity and mortality rates.
4	Sohail R, et al.	2019	Case Report	1	The study suggests that cAVM is highly prevalent in women between their third and fifth decade of life, with high cases of rupture reported during pregnancy due to elevation on estrogen level and cardiac outputs. A multidisciplinary team decided to manage the reported patient to prevent rebleeding and enable time for delivery. The patient

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					underwent glue embolization to enhance the outcome and avoid pregnancy termination. The fetal-maternal complications due to urinary tract infection causing deterioration in patient condition and possibility of bleeding led to the termination of pregnancy by hysterotomy.
5	Wei HY, et al.	2008	Case Report	1	The report presents a 32-year-old woman who was 36 weeks pregnant with persistent headache and a Glasgow Coma Scale score of 14. Brain MRI identified intracerebral hemorrhage with cerebral AVM in the right middle cerebral artery. With the presented conditions, CS was done to terminate the pregnancy and reduce bleeding associated with vaginal delivery, followed by craniotomy for the decompression of the intracranial hematoma.
6	Mehrotra M, et al.	2017	Case Report	1	The study reports a case of a 22-year-old woman, 32 weeks pregnant, with severe headache, episodes of vomiting, and a history of tonic-clonic seizures at 22 weeks. CT scan and DSA indicated giant segments of aneurysm located in the left supraclinoid internal carotid artery. Induced labor was successfully done to avoid complications of CS. The left pterional craniotomy was done, clot removed, and aneurysm clipped to prevent the anterior interhemispheric fissure rebleeding. The report indicates that rupture in a cerebral aneurysm in pregnancy, labor, and delivery is associated with the fluctuations in intracranial and blood pressure causing aneurysmal wall strain. The study concludes that even though management of aneurysms involves clipping or endovascular interventions, methods of delivery are determined by the obstetrician.
7	Mehrotra M, et al.	2017	Case Report	1	The study reports a case of a 26-year-old puerperium with severe holocranial headache, without seizures, and uncomplicated history of the antenatal period. CT diagnosis indicated subarachnoid hemorrhage (SAH), and DSA identifies a dissecting aneurysm of the posterior cerebral artery with the option of conservative management. The study links intracranial dissecting aneurysms to fibromuscular dysplasia, migraine, syphilis, trauma, polyarteritis nodosa, and oral contraceptive use. The study concluded that dissecting aneurysm in pregnancy is rare and clinically presented either as bleed or ischemic symptoms. Therefore, reliable treatments are conservative management, surgical options, and endovascular techniques based on individualized patient assessment.
8	Hironaka K, et al.	2020	Case Report	1	The study presents an incident of aneurysmal subarachnoid hemorrhage (aSAH) in a 34-year-old in her 31 <sup>st</sup> week of pregnancy with acute headache. Her severe headache

					advanced, and she fell into a coma and stopped breathing for a minute during ambulatory services. After artificial ventilation that normalized her vitals, the baby was saved through CS based on a decision by a neonatologist and obstetrician. The study indicated that surgical intervention, mainly surgical clipping is essential for aSAH in pregnancy and that brain CT and MRI should not be discouraged as a diagnostic tool at any stage of pregnancy.
9	Perez VL, et al.	2021	Case Report	1	The study reports a case of cerebral cavernoma in a 41-year-old female with 38 weeks pregnancy in a breech presentation. Major clinical manifestations of cerebral cavernoma (CC) include cerebral hemorrhages, seizures nonspecific headaches and focal neurological deficits. The study recommends that anesthetic management be used on CC pregnant patients by incorporating multidisciplinary intervention.
10	Ding D, et al.	2017	Retrospective study	8	In the study, 6 patients had brainstem CCMs, while 2 presented thalamic CCMs based on MRI indications. Neurosurgeon decision advised for a surgical approach based on location, accessibility, border, operativity, and morbidity of the lesion and procedure. The study experimented that partial CCM resection decompresses impacts of hematoma due to CCM hemorrhage, while total surgical approach maximizes long-term patient outcomes. Therefore, applying safe entry zones and imaging information on neuronavigation is fundamental to reducing operative mortality and morbidity.
11	Teik CK, et al.	2019	Case Series Report	6	The study report cases of six pregnant patients at different gestation periods with incidents of cerebral AVM between 2010 and 2017. The researchers used brain CT scan and MRI to detect AVM and their pathophysiological conditions, while cerebral angiography employed significant features of the C-AVM. Asymptomatic patients managed conservatively through multidisciplinary care for effective pregnancy outcomes. One of the symptomatic patients developed hemorrhage due to asymptomatic bleeding at 18 weeks and was successfully treated conservatively. In contrast, another was treated by embolization but developed complications due to extradural and intraventricular hemorrhages that needed multiple craniotomies leading to the death of the patient and the fetus. The study concluded that management and treatment of cerebral AVM depend on presentations and individualized management plans.

**Table 1:** The summary of the findings of the individual studies included in the study is captured in Table 1.

## Discussion

Cerebral complications or abnormalities experienced during pregnancy and puerperium have recently been evaluated with the rising applications of CT scan, DSA, and MRI [6]. These diagnostic techniques have enabled the classification of cerebral vascular malformations based on types, size, pathophysiology, clinical presentations, and location within the brain. The developments have fundamentally shaped critical decision-making in the neurosurgical and emergency departments, enhancing pregnancy outcomes and reducing mortality rates. Human research has significantly increased since 1990 due to incidental clinical phenomena ranging from study protocols, frequency, experiences, and challenges [14]. Multidisciplinary collaborations support brain imaging research and vital discoveries through information sharing across laboratories and scan reviews by physicians to eliminate false-positive findings. The documentation of the previous incidental articles enables the current articles to generate comprehensive information that aids in developing treatment options and implementing management plans for patients' benefits. Therefore, case reports, reviews, investigations, and observational records of unique clinical incidents form human research's fundamental backgrounds, leading to advanced effective and efficient clinical practices. Pregnancy and puerperium are accompanied by numerous physiological and hormonal changes that significantly influence the normal systemic and vital organ functions. The essential changes in the plasma and blood volumes, pressure, and

components to accommodate the coexistence of the mother and the fetus stimulate the overproduction of vital factors that impact routine body activities. The effects result in the risk of thromboembolism, vasodilation, and overstretch in brain regulatory activities collectively called intracranial vascular malformations. In terms of weeks or months, each gestational period experiences significant transformations that directly influence homeostatic reactions via concentration shifts in essential body fluids. The abrupt changes in the hormonal secretions during postpartum create a window of hormonal imbalance that opens opportunities for risks and complications. In critical cases, the abrupt molecular changes among women during pregnancy and puerperium periods innovate an environment that supports neurological deterioration, specific to every pregnancy. Thus, presenting clinical manifestations that require specific management and diagnostic evaluation. The review describes three types of cerebral vascular malformations at risk of complications during pregnancy and puerperium periods. These include cerebral cavernoma malformation, cerebral arteriovenous malformation, and incidental cerebral aneurysm classified according to hemodynamics and pathologically impacted blood vessels. As illustrated by different literature reviewed, identifying these particular abnormalities is critically based on individual characteristics or morphology and imaging-related factors. That is, the pathological indications in the cerebral parenchyma, pathological morphology and networks in the nidus, venous drainage linked to arteriovenous shunt, and the origins of the

impacted blood vessels. The specific features of individual malformation are related to the advanced diagnostic mechanisms, particularly the brain's DSA, CT, and MRI imaging. The imaging techniques are influenced by suspected case: for pathologic blood vessel cases, CT angiography, Time of Flight MR angiography, and contrast-enhanced MR angiography are considered; for acute, subacute, and old hemorrhages, native CT, Fluid-attenuated-inversion-recovery (FLAIR) imaging and susceptibility imaging are golden; hemodynamics opts time-of-flight MR angiography; while brain edema T<sub>2</sub> weighted imaging, native CT and FLAIR imaging [3]. The digital subtraction angiography and CT and MRI are used to provide detailed information for the critical assessment of the malformation in terms of risks of hemorrhage, intolerable presentations, and danger of pathophysiology. As indicated in the selected studies reviewed, the risk associated with each cerebral malformation during pregnancy and puerperium essentially differs in outcomes and initial intervention. With low prevalence in the disease's occurrence among expectant women, the development of management criteria ensures accurate results in the global medical sphere remain sophisticated. The case series by [14] present six patients with cerebral AVM during pregnancy, managed differently, leading to many outcomes. Five of the participants reported successful pregnancies associated with management options considered effective for every individual patient. The reported maternal death was attributed to advanced complications of extradural and intraventricular hemorrhages accompanied

by persistent headache and vomiting [14]. Hironaka et al. [11] argue that severe hemorrhages and constant headaches promote a gradual increase in internal blood pressure, resulting in internal bleedings caused by tiny capillaries and blood vessels ruptures. In comparison, persistent vomiting initiates a negative pressure within the system by creating a window of fluid imbalances. It directly influences the functions of the sodium-potassium pump and reduces placenta exchange rates [11]. This instantly suffocates the fetus and major organ shutdown during pregnancy because of reduced gaseous exchange and elimination of waste materials. Therefore, systemic confusion is ascribable to the multiple responses the system requires simultaneously, promoting the development of autoimmune reactions. During pregnancy, management of the mentioned cerebral condition targets successful outcomes on the mother and the growing fetus. Before any neurosurgical procedure is applied to the patient, critical considerations are made on the fetus's condition and wellbeing before and after the selected intervention. As witnessed in most of the cases presented in this review, critical neurosurgical procedures that may result in significant complications are executed by initially terminating pregnancy through CS or induced labor. Kasper et al. [18] describe that elective CS is the most commonly preferred delivery method among pregnant women identified for brain surgery. CS maintains the patient's blood pressure stability, enables assessment of neurological condition, and maintains isotonic state through fluid resuscitation [18-20]. Therefore, most successful neurosurgical

procedures involving CCM, cerebral AVM, and incidental cerebral aneurysm during pregnancy considered the safety of the baby or fetus through elective CS, followed by brain surgery within the same day or days-weeks or months later. The management and treatment of these sophisticated and risky conditions are highly challenging and complicated, in addition to the hormonal influences during pregnancy and puerperium. Several factors that require multidisciplinary decision-making through consensus determine effective and efficient management.

The reviewed studies show that effective management and treatment mechanisms of cerebral abnormalities involve conservative and interventional treatments. Conservative treatments aim to reduce the risk factors by administering pharmacological and non-pharmacological implements, while interventional involves surgical resection, clipping, craniotomy, embolization, evacuation, extirpation, and dissection. Choosing the effective tool and method essential for the neurosurgical procedure critically depends on patient presentation, desired outcomes, and risk-benefit analysis [9]. In the reviewed studies, neurosurgical interventions were considered adequate due to successful application in different cases,

yielding positive long-term outcomes for both patient and the fetus.

## Conclusion

This systematic review identified that CCM, C-AVM, and incidental cerebral aneurysms are rare brain abnormalities during pregnancy and puerperium. The complications presented by these conditions risk the life of both mother and the fetus. Although no direct association has been established that pregnancy and puerperium contribute to the development and progression of cerebral malformations, significant physiological changes and natural history create a neurological imbalance environment that risks the occurrence. Neurosurgical management of cerebral vascular abnormalities remains the most preferred treatment intervention for symptomatic patients. Successful implementation of neurosurgical intervention involves multidisciplinary consensus regarding individual patient presentation and morphological characteristics. Therefore, it was established that successful management and outcomes of the neurosurgical techniques are met by an independent, specific, and unique management plan for every case to eliminate or reduce risk factors.

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