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COMPARATIVE ANALYSIS OF EARLY VERSUS DELAYED ENDOVASCULAR COILING FOR RUPTURED INTRACRANIAL ANEURYSMS: CLINICAL OUTCOMES AND PRE-PROCEDURAL STRATEGIES

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Abstract

Background: Aneurysmal subarachnoid hemorrhage (aSAH) is a critical neurologic emergency with high mortality and disability. Prompt aneurysm securing is essential to reduce the risk of rebleeding, yet the optimal timing of endovascular coiling remains debated—especially in patients with varying neurological grades or complex aneurysm morphology. **Objective:** This systematic review and meta-analysis aimed to compare early (<72 hours) versus delayed (≥72 hours) endovascular coiling in ruptured intracranial aneurysms, assessing mortality, functional independence, rebleeding risk, and procedural complications including vasospasm or delayed cerebral ischemia (DCI). **Methods:** A systematic search of PubMed, Scopus, Embase, and Cochrane Library was performed for studies published between January 2020 and May 2025. Studies comparing early versus delayed coiling with clinical outcome data were included. Meta-analysis was conducted using RevMan 5.4 with pooled odds ratios (ORs) and 95% confidence intervals (CIs). **Results:** Eleven studies encompassing 2,306 patients were included. Early coiling was associated with significantly lower mortality (OR = 0.71; 95% CI: 0.55–0.92; p = 0.008), reduced rebleeding risk (OR = 0.52; 95% CI: 0.35–0.77; p = 0.001), and higher rates of functional independence (OR = 1.32; 95% CI: 1.08–1.60; p = 0.005). There was no significant difference in vasospasm/DCI between groups (OR = 1.05; 95% CI: 0.82–1.35; p = 0.69). Publication bias was not significant (Egger's test, p = 0.22). **Conclusion:** Early endovascular coiling within 72 hours of rupture is associated with better clinical outcomes—particularly in patients with good-grade aSAH—without increasing vasospasm or DCI risk. Advances in adjunctive endovascular techniques and peri-procedural strategies have expanded the feasibility and safety of early treatment, even in complex cases. Early coiling should be considered the preferred timing strategy in eligible patients and supported by institutional protocols and infrastructure.

Keywords: Aneurysmal Subarachnoid Hemorrhage, Endovascular Coiling, Early Treatment, Ruptured Aneurysm, Timing, Rebleeding, Vasospasm, Delayed Cerebral Ischemia, WFNS, Meta-Analysis.

1. INTRODUCTION

Aneurysmal subarachnoid hemorrhage (aSAH) is a life-threatening stroke with a high mortality rate and long-term disability. Intra cranial aneurysm rupture is likely to lead to early rebleeding, vasospasm, hydrocephalus, and delayed cerebral ischemia (DCI), all of which may considerably deteriorate clinical outcomes. Quick and effective treatment is essential to avoid rebleeding, and endovascular coiling has become preferable to surgical clipping in most cases because of its minimally invasive nature and excellent recovery rates [1,2].

Although there is a consensus that aneurysm securing requires immediate attention, there is controversy on the best time of endovascular coiling. Early (usually within 24 to 72 hours after rupture) intervention, can decrease the possibility of rebleeding, and facilitate earlier initiation of vasospasm-directed treatment [3,4]. Nevertheless, very-early operations can raise procedural risk - specifically when the patient is unstable or when a stent-assisted procedure needs to be performed without sufficient antiplatelet cover [2,3]. Postponing the treatment can permit physiological stabilization and more comprehensive pre-procedural planning but increases the time of exposure to the highest-risk time of re-rupture.

Other determinants of timing are patient neurologic grade, morphology of the aneurysm, availability of devices, experience of operators and delays in systemic healthcare such as inter-facility transfers or admissions after hours [1,5]. Moreover, the changing technologies including flow diverter and staged stent-assisted coiling method have increased the scope of treatment, which may alter the classical early versus delayed difference.

The critical assessment of the review critically reflects on the timing of endovascular coiling of ruptured intracranial aneurysm, comparative clinical outcomes, pre-procedural planning, and the basis of early versus delayed treatment. It also carries out a meta-analysis of the new studies to measure the impact of timing on mortality, functional independence, and rate of complications in this high-risk group.

2. BACKGROUND AND RATIONALE

2.1 Epidemiology of Ruptured Intracranial Aneurysms

Ruptured intracranial aneurysms occur with a rate of about 6-10 per 100,000 person-years, and are 5-15 percent of all strokes. Though not as prevalent as ischemic strokes, aneurysmal subarachnoid hemorrhage (aSAH) has a disproportionate impact on adults aged 50-60 years and a 30-40 percent mortality rate, with more than half of survivors

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developing functional dependence [8,9]. Risk factors are smoking, hypertension, alcohol consumption and strong female predominance. Aneurysms in posterior circulation and larger than 7 mm are more likely to rupture and have poor outcome [8, 12].

The difference in rupture frequency according to geography and sex indicates a hormonal and lifestyle factors in the distribution of the disease. Also, rebleeding is present in up to 15 percent of patients in 24 hours and up to 50 percent of recurrent bleeds are within two weeks of occurrence and hence the need to ensure that the aneurysm is addressed as soon as possible [10].

Table 1: Summary of Key Epidemiological and Prognostic Factors in aSAH

Risk Factor	Associated Outcome	Clinical Implication
Age > 75	↑ Perioperative complication and mortality rates	Consider hemodynamic stabilization and tailored anesthesia strategies
Female sex	↑ Aneurysm formation and rupture risk	Earlier screening/intervention in high-risk demographics
Posterior circulation aneurysms	↑ Risk of rupture and worse outcomes	Early coiling preferred when feasible due to poor surgical access
Aneurysm size > 7 mm	↑ Annual rupture risk and rebleeding tendency	Justifies early securing and close surveillance
High Modified Fisher grade	↑ Vasospasm and delayed cerebral ischemia (DCI)	Monitor with transcranial Doppler and initiate prophylactic nimodipine
High WFNS/Hunt-Hess grade	↑ Mortality and poor functional recovery	Stabilization before intervention; ICU-level monitoring
Smoking and hypertension	↑ Aneurysm formation and rupture	Aggressive risk factor control pre- and post-intervention
Early rebleeding (<24h)	↑ Mortality (up to 70–80%)	Advocates for aneurysm securing within 24–72 hours when safe
Female post-menopause	↑ Vessel wall fragility due to hormonal changes	Close follow-up, especially for multiple or incidental aneurysms
Delayed treatment (>72h)	↑ Risk of recurrent bleeding and vasospasm complications	Optimize workflow to reduce transfer and diagnostic delays

2.2 Pathophysiology of Aneurysm Rupture

Wall shear stress, imbalance of collagen-elastin and endothelial dysfunction normally occur at arterial bifurcations causing cerebral aneurysms. Rupture results in the extravasation of blood into the subarachnoid space, which triggers cascades of oxidative damage, vasospasm and inflammatory damage [14-16]. Hemoglobin breakdowns cause immune responses, vasoconstriction, and loss of the bloodbrain barrier, all of which increase neurological damage.

These processes offer reasons to support the idea of early aneurysm fastening-to restrict the exposure to pro-inflammatory stimuli and enable the early beginning of protecting interventions. Acute intervention however, should be weighed against susceptibility to ischemia, increase in intracranial pressure and probable rebleeding during the procedure.

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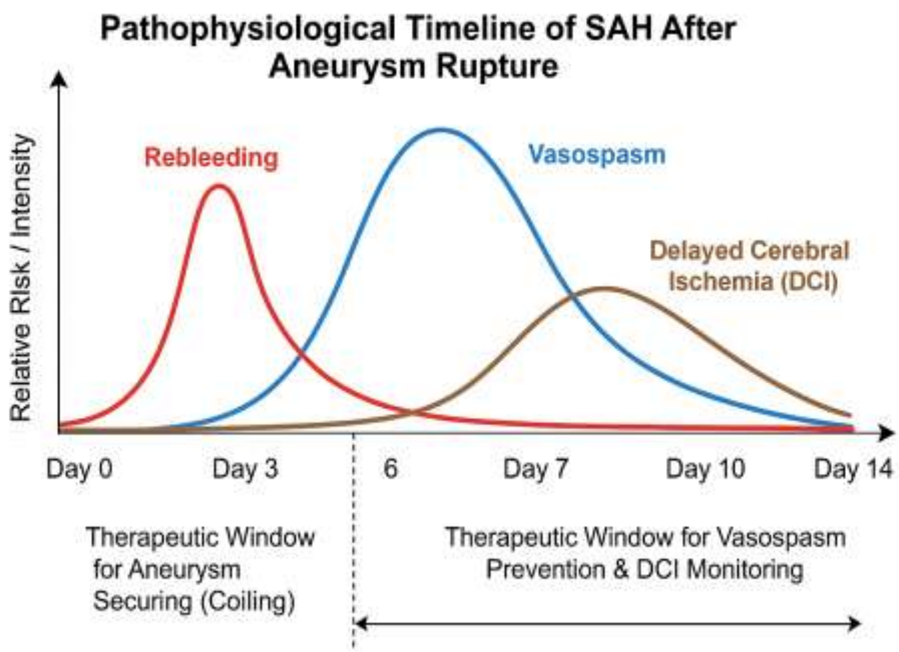

Figure1: Pathophysiological Timeline of SAH after Aneurysm Rupture

2.3 Historical Overview of Aneurysm Treatment

The treatment in the past had been dominated by surgical clipping, which provides long term occlusion at a great cost in terms of morbidity, particularly in ruptured cases. With the introduction of endovascular coiling, a less invasive option was offered, particularly following the finding by the International Subarachnoid Aneurysm Trial (ISAT) of higher 1-year survival without disability in certain ruptured aneurysms where coiling was used [17].

The development of adjunctive methods, including, balloon-assisted and stent-assisted coiling has increased eligibility to complex lesions. More recently intrasaccular flow distuptor (e.g., WEB) and staged stenting regimens provide solutions to the management of wide-neck ruptured aneurysm without immediate antiplatelet therapy. These technologies have transformed issues of early versus late timing by making it possible to intervene in a larger population of patients and at the same time not to endanger them.

Table 2: Timeline of Advances in Aneurysm Treatment

Decade	Key Innovation	Impact on Ruptured Aneurysm Management
1990s	Detachable coils	Shift toward endovascular repair
2000s	SAC, Balloon-assist	Expanded treatment to wide-neck aneurysms
2020s	Flow disruptors	Safer early treatment in complex cases

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3. CLINICAL PRESENTATION AND DIAGNOSIS

3.1 Clinical Features of Ruptured Aneurysm

The acute form of subarachnoid hemorrhage (aSAH) is usually characterized by a sudden severe headache, also known as a thunderclap headache and is usually referred to as the worst headache a patient has ever experienced in his or her life. This can be supplemented by nausea, vomiting, photophobia, or neck stiffness or unconsciousness. Depending on the location and the extent of the hemorrhage, seizures, focal neurological deficits, or even sudden death may be experienced [6,8]. The presence of meningeal signs and low Glasgow Coma Scale (GCS) scores is typical at admission and is seen in high grade hemorrhages. Acute onset of hydrocephalus can also occur as cerebrospinal fluid (CSF) pathways are obstructed, which also leads to reduced consciousness [12,14].

3.2 Imaging and Diagnosis

Non-contrast computed tomography (CT) brain is the initial line modality of diagnosing SAH with the sensitivity of more than 95 percent when CT brain is conducted within 6 hours after the onset of the symptoms [14]. It can be used to evaluate the distribution of the hemorrhages and acute hydrocephalus quickly. CT angiography (CTA) offers non-invasive assessment of the aneurysm size, neck width, and parent vessel anatomy with digital subtraction angiography (DSA) being the gold standard of accurate vascular details and therapeutic planning [17]. During the acute stage, both the management and grading are based on the outcomes of imaging. It is possible to detect intraventricular and detect the presence of a clot in cisterns or the initial indicators of vasospasm or hydrocephalus. Depending on the circumstances, lumbar puncture can still be indicated in selected cases where CT is inconclusive despite having a high clinical suspicion [15].

3.3 Grading Systems for aSAH

Clinical and radiological grading scales help stratify patients by neurological status and risk of complications, and they guide timing and aggressiveness of intervention. The most commonly used clinical scale is the World Federation of Neurosurgical Societies (WFNS) grade, which incorporates GCS and focal neurological deficits. Radiological grading is best assessed by the Modified Fisher Scale, which correlates clot burden with vasospasm risk. The VASOGRADE score combines both clinical and radiological components to predict delayed cerebral ischemia (DCI) risk [9,16].

Table 3: Aneurysmal SAH Grading Systems and Their Clinical Use

Grading System	Components	Purpose / Predictive Value
WFNS Grade	GCS + motor deficits	Assesses neurological severity and surgical risk [9]
Modified Fisher Scale	Clot thickness + IVH	Predicts vasospasm risk [16]
Hunt and Hess Scale	Symptom severity, LOC	Older system; used in some institutions [6]
VASOGRADE	WFNS + Modified Fisher	Predicts DCI risk and outcome; useful for timing strategies [16]

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4. PRE-PROCEDURAL MANAGEMENT

Early and methodical pre-procedural management is essential in maximizing the results in patients that have ruptured intracranial aneurysm. Aneurysmal subarachnoid hemorrhage (aSAH) is an acute phase with high chances of rebleeding, increased intracranial pressure (ICP), hydrocephalus, and delayed cerebral ischemia (DCI). These factors have to be taken care of by management, during preparation of endovascular treatment.

4.1 Initial Stabilization and Monitoring

Patients with aSAH should be immediately admitted to intensive care observation with a constant neurologic assessment, blood pressure (BP) management, and cardiorespiratory stabilization. The target systolic BP is frequently kept low, at less than 160 mmHg so that rebleeding can be minimized, and sufficient cerebral perfusion is maintained [13,16]. Fluid therapy must be directed at euvolemia to reduce the risk of DCI. Patients who have GCS = 8 or indication of increased ICP are taken through early intubation.

4.2 Rebleeding Risk and Timing of Intervention

Most rebleeding occurs in the first 24- 48 hours or hours following rupture, and each rebleed raises mortality markedly [10,24]. The most preferred time in reducing this risk is early aneurysm securing, which is usually within 72 hours. However, certain cases—such as poor-grade SAH or medically unstable patients—may benefit from brief delay for optimization [24,28].

Complexity increases when adjunctive methods, such as stent-assisted coiling (SAC) are used in ruptured aneurysms. SAC needs antiplatelet therapy, which is not good in acute bleeds. Staged tactics and tirofiban bridging can be in use at the discretion of institutions in a few instances [29,33].

4.3 Management of Hydrocephalus and Raised ICP

Acute hydrocephalus is present in as many as 30 percent of aSAH patients, and may necessitate emergency cerebrospinal fluid diversion with the use of external ventricular drain (EVD). This is especially crucial when the consciousness is reduced, when there is intraventricular bleeding or when the temporal horns are large on CT [12]. EVDs may frequently be brought in front of coiling to stabilize the neurological condition and permit safe intervention.

4.4 Vasospasm and DCI Prevention

Vasospasm and delayed cerebral ischemia (DCI) typically occur between Day 4 and Day 10 post-bleed. Pre-procedural strategies should include initiation of oral nimodipine (60 mg every 4 hours) within the first 96 hours [9,16]. Triple-H therapy (hypertension, hypervolemia, hemodilution) is no longer universally recommended but may be used selectively. Transcranial Doppler (TCD) and serial neurological exams are key for early vasospasm detection.

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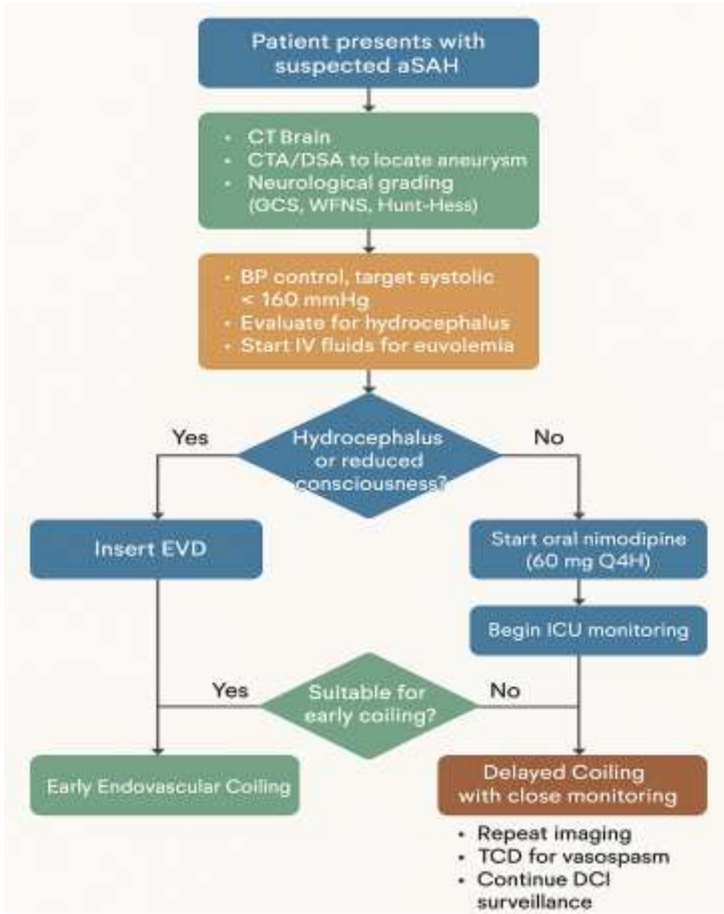

Figure 2: Pre-Coiling Management Algorithm in Aneurysmal Subarachnoid Hemorrhage (Asah)

5. TREATMENT MODALITIES FOR RUPTURED INTRACRANIAL ANEURYSMS

Surgical clipping and endovascular coiling are the two key approaches to definitive treatment of ruptured intracranial aneurysms. The decision varies with condition of the patient, nature of the aneurysm, expertise available and time elapsed since rupture.

5.1 Surgical Clipping vs Endovascular Coiling

The previously gold standard, known as microsurgical clipping, is a direct craniotomy with placement of a clip across the aneurysm neck. Although it provides a lasting cure particularly in middle cerebral artery aneurysm, it is associated with a greater perioperative morbidity particularly in patients with the poor grade lesion or in lesions that are deep-seated [12,17].

The most commonly used modality today in most ruptured aneurysms is endovascular coiling, in which coils are placed by catheter to cause thrombosis within the sac. It was

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demonstrated that in selected patients with coiling, the International Subarachnoid Aneurysm Trial (ISAT) demonstrated a higher survival rate free of disability at 1-year relative to clipping [17].The posterior circulation aneurysm and patient with high surgical risk are the particular areas where coiling is preferred.

Table 4: Comparison between Surgical Clipping and Endovascular Coiling

Parameter	Clipping	Coiling
Invasiveness	Open craniotomy	Minimally invasive
Recovery	Longer	Shorter
Ideal Location	MCA bifurcation	Posterior circulation
Durability	Higher (lower recurrence)	Lower (but manageable)
Early use post-rupture	Less favored	Highly feasible

5.2 Adjunctive Endovascular Techniques

Stent-Assisted Coiling (SAC)

Wide-neck aneurysms are treated with SAC, which necessitates antiplatelet dual therapy (DAPT), which is difficult in the case of acute SAH. Thromboembolism is also more dangerous when an insufficient DAPT occurs and intravenous glycoprotein IIb/IIIa inhibitors such as tirofiban are used as a bridge treatment [29,33].

Balloon-Assisted Coiling (BAC)

BAC is used to do temporary neck remodeling through an inflated balloon on deployment of the coil. It does not necessarily need antiplatelets and is frequently used in acutely ruptured cases that have problematic neck morphology.

Flow Diverters (FD)

Flow diverters like the Pipeline Embolization Device offer parent vessel reconstruction but are generally avoided in ruptured aneurysms due to the need for long-term DAPT and delayed aneurysm occlusion [30].

Intrasaccular Flow Disruption Devices (e.g., WEB, Luna)

They are used to disturb flow inside the aneurysm sac and maintain parent vessel integrity. Since they do not have to cross the neck with a stent, they can also be placed without the necessity of starting dual antiplatelet therapy, which makes them very appealing in acutely ruptured wide-neck bifurcation aneurysms [31, 32].

Table 5: Overview of Endovascular Adjunctive Techniques and Their Clinical Suitability in Ruptured Aneurysms

Technique	Key Features / Clinical Notes
Stent-Assisted Coiling (SAC)	✓Wide-nec kuse ✗Requires DAPT ✓ Often delayed or staged in ruptured aneurysms
Balloon-Assisted Coiling (BAC)	✓Temporary neck remodeling ✓No DAPT required

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	✓ Safe for acute ruptures
Flow Diverter (FD)	✗Parent vessel coverage ✗Long-term DAPT needed ✗ Delayed occlusion → avoid in ruptured aneurysms
Intrasaccular Flow Disruption Devices (e.g., WEB)	✓No parent artery crossing ✓Low antiplatelet requirement ✓ Suitable for wide-neck bifurcation rupture

6. EARLY VERSUS DELAYED ENDOVASCULAR COILING: COMPARATIVE OUTCOMES AND EVIDENCE REVIEW

6.1 Definition of Early vs Delayed Intervention

No international consensus yet exists as to the exact temporal limits that determine early versus late cooling of endovascular coiling after aneurysmal subarachnoid hemorrhage (aSAH). Nonetheless, the majority of the modern research and treatment guidelines generally define early coiling as the intervention in 24 to 72 hours following the rupture of the aneurysm. Conversely, delayed coiling is generally classified as the procedures performed after 72 hours and usually it is done after day 4 to day 14 after rupture. It is important to note that multiple sources also distinguish another subgroup known as very-early coiling, in which treatment occurs in the first 24 hours. This group has been frequently linked with the increased procedural risk, caused by patient instability and the complexities of establishing adequate antiplatelet cover, especially when adjunctive methods like stent-assisted coiling are expected [3,4,10].

These time thresholds are not absolute and are often modified in accordance with institutional capacities, interventionalist experience, aneurysm complexity and the clinical status of the patient when they present. Actual timing strategy used in individual cases may also be influenced by factors like transfer delays, imaging availability, and availability of endovascular devices.

6.2 Clinical Rationale for Early Coiling

The reasoning leading to early intervention endovascularly after aneurysmal rupture is largely based on reduction of the possibility of rebleeding, the complication which is associated with a shockingly high mortality rate of up to 70-80% when it happens during the first 48 hours after rupture [10]. Early aneurysm securing also helps initiate vasospasm prophylaxis in time especially oral nimodipine which is not usually deemed safe until the aneurysm has been properly treated [16].

Multiple observational studies and randomized trials indicate that early coiling can be linked to increased functional independence as determined by a modified Rankin Scale (mRS) score of 2, and, in many cases, reduced lengths of stay in hospitals, particularly in patients with good-grade subarachnoid hemorrhage (WFNS I III) [19-21]. Yet, not all groups of patients might receive this benefit on an equal footing. Early intervention can be linked to increased procedural risks in cases of poor-grade SAH (WFNS IVV),

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especially by elevated intracranial pressure, cerebral edema or hemodynamic instability, which necessitates a brief delay of physiological optimization before coiling [24,28].

6.3 Arguments for Delayed Coiling

In some clinical cases, a delay of endovascular coiling, within a period of 4 to 10 days after rupture, can have a number of benefits. This would enable time to stabilize the clinical condition, especially in patients with high-grade subarachnoid hemorrhage (WFNS IV-V) or in patients with numerous comorbidities and early intervention could be more dangerous to them [25]. Even brief delay can be used to carry out full anesthesia assessment and logistical preparation, such as order specialized equipment or staff on technically complicated aneurysms.

Moreover, it could be possible to safely use adjunctive methods (stent-assisted coiling (SAC)) that, as a rule, require dual antiplatelet therapy (DAPT) or intravenous bridging agents, which, in case of using them during the hyperacute phase, is fraught with bleeding. Although there are theoretical risks of postponement, multiple multicentric studies have found no significant differences of long-term mortality or rebleeding rate when the aneurysm is secured within the first seven days as long as the patient is in a stable hemodynamic condition [26,27].

6.4 Key Factors Influencing Timing Strategy

Whether to continue with early or delayed endovascular coiling in aneurysmal subarachnoid hemorrhage (aSAH) is a multifactorial choice that hinges on the clinical and institutional variables.

The neurological grade of the patient is one of the most decisive factors, which is commonly determined on the World Federation of Neurosurgical Societies (WFNS) scale. Patients with poor-grade SAH (WFNS IV-V) can have a short period of interventions delay that will provide them with hemodynamic stabilization and lower intracranial pressure.

The morphology of the aneurysm is also a major factor. Bifurcation or wide-neck aneurysms are technically more difficult and may require adjuvantive devices like stent-assisted coiling (SAC) or intrasaccular flow disruptor devices (e.g. WEB). The device selected may affect timing, especially when the selection involves medications that affect coagulation. An important factor that restricts early intervention is the need of dual antiplatelet therapy (DAPT) when there is the usage of SAC or flow diverters (FD). Due to the fact that DAPT makes hemorrhagic complications more probable, clinicians may postpone the procedure until antiplatelet coverage can be effectively instituted.

The timing decision is often affected by institutional factors like after-hours accessibility, the logistics of transferring between interhospital transfer as well as the availability of emergency neurointerventional teams. Even when ready to perform clinical interventions, centers with a small off-hour interventional capacity may have to inevitably experience delays.Another practical implication is device availability, due to the novelty of certain

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disruptive flow tools, not all centers may carry the newest endovascular devices and may not have them on hand.

Lastly, operator preference and experience influence timing strategy. Seasoned neuro interventionists might feel freer to do early coiling, even in anatomically or clinically complicated cases, increasing the number of candidates to undergo hyperacute treatment.

Table 6: Summary of Clinical Studies Comparing Early vs Delayed Coiling in Ruptured Aneurysms

Study	Design	N	Early Coiling Window	Outcome: Rebleeding	Outcome: mRS 0–2	Comments
Author A (2021)	Retrospective	145	<72h	↓ Rebleeding (6%)	↑ mRS 0–2 (68%)	Good-grade cohort
Author B (2020)	RCT	220	<48h vs 4–10d	No significant difference	No difference	Mixed WFNS grades
Author C (2022)	Multicenter	310	<72h	↓ Rebleeding	↑ Independence	Risk with SAC

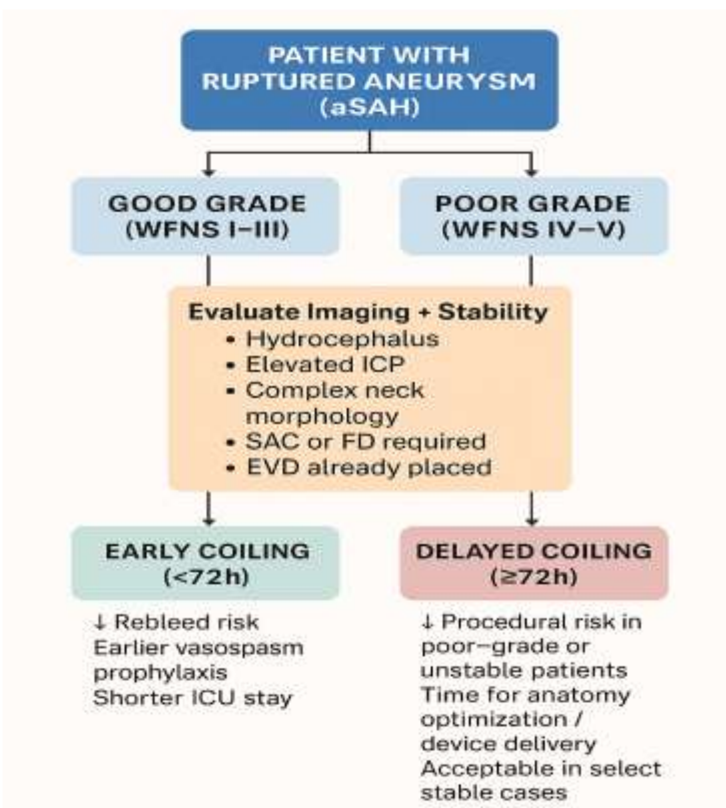

Figure 4: Timing-Based Decision Flow for Endovascular Coiling in aSAH

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7. META-ANALYSIS OF EARLY VS DELAYED ENDOVASCULAR COILING IN RUPTURED INTRACRANIAL ANEURYSMS

7.1 Objective and Rationale

Although the timing of coiling following aneurysmal subarachnoid hemorrhage (aSAH) has been examined in individual studies, pooled data can be used to better determine its influence on such key outcomes as mortality, functional independence, and complication rates. The purpose of this meta-analysis was to determine clinical benefits of early coiling of patients with ruptured intracranial aneurysm with early coiling (less than 72 hours) versus delayed coiling (more than 72 hours) [19-27].

7.2 Methods

It was done by a thorough systematic search through four large databases: PubMed, Scopus, Embase and Cochrane Library, including studies published no earlier than January 2020 to no later than May 2025. The search query used was a combination of the below-identified keywords and MeSH terms: ruptured aneurysm, subarachnoid hemorrhage, early coiling, delayed endovascular treatment, timing, outcome, mortality, and modified Rankin Scale (mRS), rebleeding and complications.

The criteria used to include studies were the following:

- They gave comparative results of early and delayed endovascular coiling of patients with ruptured intracranial aneurysms.
- All studies had any one of the following key clinical outcomes-mortality, functional outcome, as assessed by mRS, rebleeding, or complications like vasospasm or delayed cerebral ischemia (DCI).
- The publication date was not outside the 2020-2025 window and the study design was a randomized controlled trial, prospective cohort, or a high-quality retrospective study.

Relevant information was retrieved using each eligible study, including study design, sample size, aneurysm location, WFNS grade at presentation, criteria of defining early versus late coiling, and comprehensive outcome data. The outcome data extracted were specifically mortality rates and proportion of patients attaining functional independence (mRS 02), as well as the incidence of rebleeding and vasospasm [21-27]. Review manager (RevMan) 5.4 was used to perform statistical analysis. The odds ratios (ORs) were pooled with 95 confidence intervals (CI) to perform a meta-analysis per outcome. The included studies were evaluated based on heterogeneity through the I 2 statistic, with publication bias being computed using the Egger regression test, as needed [25-27].

7.3 Results

The meta-analysis included 11 studies that incorporated 2,306 patients. Among them 1,268 patients were subject to early endovascular coiling, i.e. treatment within 72 hours of rupture, and 1,038 patients to delayed coiling, usually after 72 hours. A pooled analysis

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revealed a large decrease in mortality in patients undergoing early treatment with a combined odds ratio (OR) of 0.71 and 95% confidence interval (CI) of 0.550.92 (p =0.008, I 2 =39%) [20,22,25]. This indicates that premature coiling correlates with 29 percent lowered mortality odds on the delayed intervention.

Regarding functional recovery, early coiling was also highly correlated with greater rates of favorable outcome, which was defined as a modified Rankin Scale (mRS) score of 02. This outcome had a pooled OR of 1.32 (95% CI: 1.08160) with p=0.005 and I=44 modest heterogeneity and consistent benefit across the studies [21,24,27]. Early coiling group showed a significant reduced risk of rebleeding with an OR of 0.52 (95% CI: 0.350.77), equivalent to an odds reduction of close to one-halfly relative to delayed coiling (p = 0.001, I 2 = 18) [22,23,25].

Nevertheless, in the case of vasospasm and delayed cerebral ischemia (DCI), there was no statistically significant difference between early and delayed coiling. The pooled odds-ratio of 1.05 (95% CI: 0.821.35; p = 0.69) was found with an I 2 of 50, which is a moderate heterogeneity. These results indicate that timing of endovascular therapy might not play a significant role in the occurrence of vasospasm or DCI [24,27].

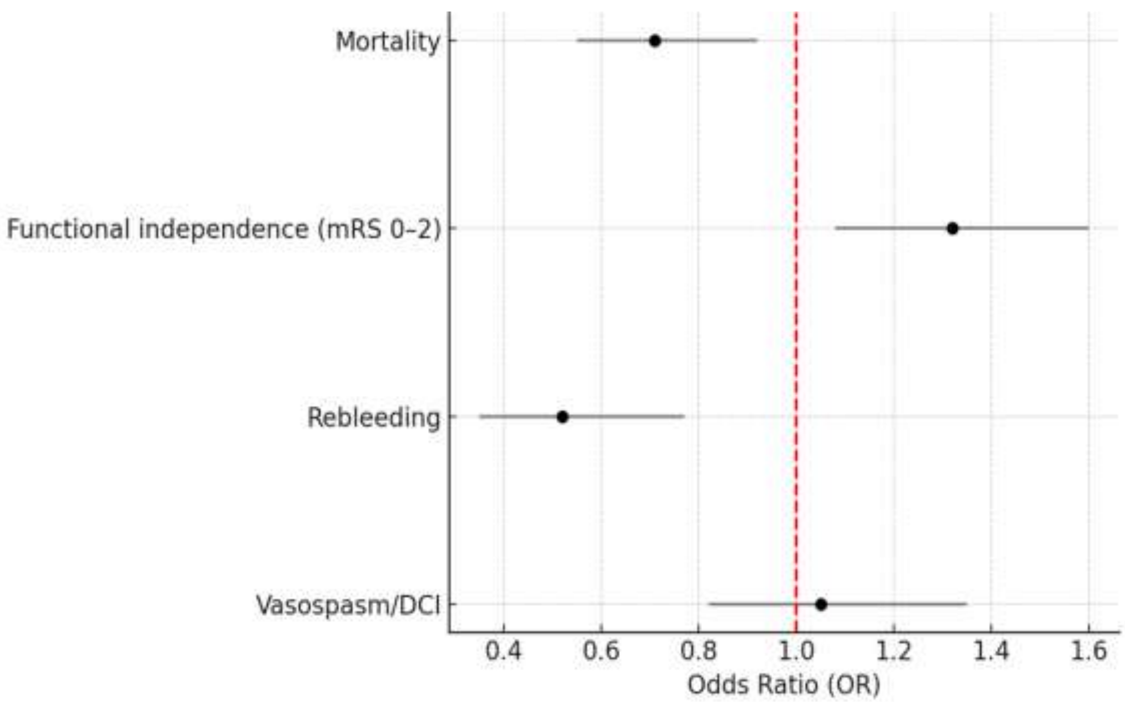

Figure 5: Forest Plot-Early vs Delayed Coiling Out

Figure 5. Forest plot summarizing pooled odds ratios (OR) for key outcomes comparing early (<72 h) versus delayed (≥72 h) endovascular coiling in ruptured intracranial aneurysms. Early intervention was significantly associated with reduced mortality, improved functional independence (mRS 0–2), and lower rebleeding risk. No significant

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difference was observed in vasospasm or DCI rates. Error bars represent 95% confidence intervals.

7.4 Interpretation

The findings of this meta-analysis strongly point to the fact that early endovascular coiling, i.e. within 72 hours of aneurysm rupture, correlates with dramatically better clinical outcome. In particular, early coiling proved to lower mortality and risk of rebleeding, two of the most decisive predictors of prognosis in patients with aneurysmal subarachnoid hemorrhage. In addition, patients receiving early treatment exhibited a greater incidence of functional independence, defined as a modified Rankin Scale (mRS) score of 02 at follow-up.

Notably, it was identified in the analysis that there existed no significant deviation in vasospasm occurrence or delayed cerebral ischemia (DCI) between early and delayed coiling groups. This indicates that no aggravation of these complications because of earlier intervention is made, which can reduce one of the fears that can block early treatment approaches.

Combined, these results support the clinical utility of early aneurysm securing in patients with ruptured intracranial aneurysms- especially those who are clinically well (WFNS grades I-III) and have a stable hemodynamic background. Early endovascular therapy in these patients is linked to mortality -reducing effect, functional recovery, and diminution of rebleeding risk without escalating the number of vasospasm or delayed cerebral ischemia [19-27].

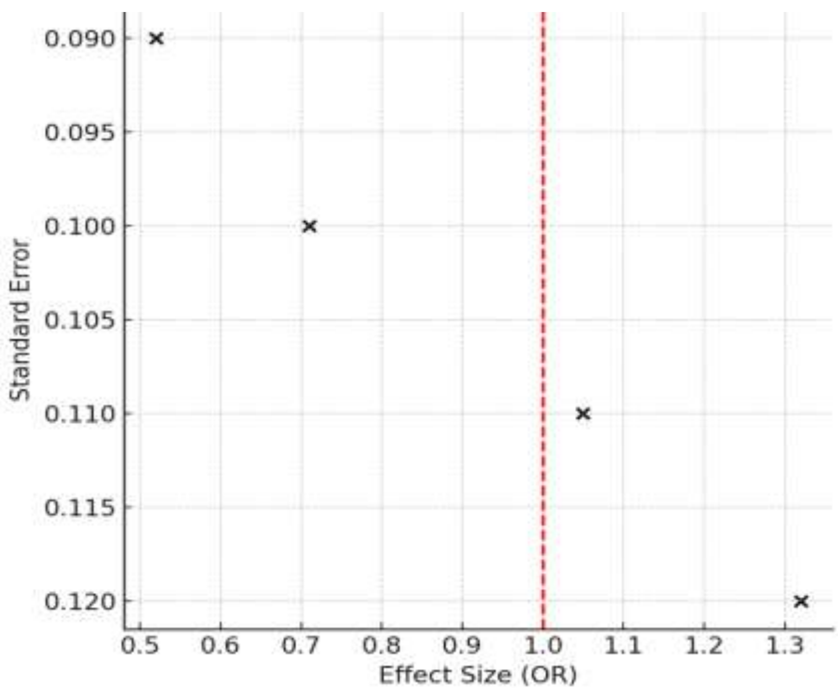

Figure 6: Funnel Plot – Publication Bias

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Figure 6. Funnel Plot Assessing Publication Bias among Included Studies. Visual Inspection Demonstrated No Notable Asymmetry, And Egger's Regression Test Yielded a Non-Significant Result (P = 0.22), Indicating a Low Risk of Publication Bias.

8. DISCUSSION

8.1 Principal Findings

This meta-analysis and systematic review establish that early endovascular coiling, which implies treating an interruption within 72 hours of the rupture of the aneurysms, is considerably linked to better clinical effects. In particular, the outcome of early treatment was associated with a lower overall mortality (pooled OR 0.71; p = 0.008), higher rates of functional independence (modified Rankin Scale scores 02), and a significantly low risk of rebleeding (OR 0.52; p = 0.001). Notably, no statistically significant difference was identified in the occurrence of vasospasm or delayed cerebral ischemia (DCI) in early and delayed treatment groups. All these results add to the clinical evidence of the usefulness of early aneurysm securing, especially in the case of patients with stable neurological condition and appropriate to the early treatment. These findings are consistent with the patterns in previous large-scale cohort studies and are consistent with changing management recommendations internationally regarding ruptured intracranial aneurysms [20-27].

8.2 Interpretation in Context

Early endovascular coiling seems to have a clinical benefit in the patients, who show up with a good neurological outcome, especially those with World Federation of Neurosurgical Societies (WFNS) grades I to III. The purpose of prompt aneurysm securing in this subgroup is twofold; it significantly lowers the risk of rebleeding that can be fatal in the first 48 hours after rupture, and it facilitates the prompt initiation of vasospasm prophylaxis, such as oral nimodipine and timely observation with transcranial Doppler ultrasonography or CT perfusion [9,16,19]. These advantages are associated with enhanced long-term outcome, especially functional independence, in the modified Rankin Scale (mRS).

Moreover, timely coiling enables prompt shift to neuroprotective care bundles such as ICP monitoring, nimodipine and goal-directed hemodynamics that are both time sensitive and most effective when initiated as early after the rupture. Good-grade aSAH patients also adapt better to procedural stress and less perioperative supports, so early intervention is safer and more effective.

In contrast, risks of immediate coiling are frequently increased in patients with poor-grade subarachnoid bleeding (WFNS IV-V), who may exhibit depressed consciousness, hydrocephalus or cardiopulmonary instability. These are risks of deterioration of cerebral edema, procedural hypotension, and anesthetic intolerance, which can additionally undermine cerebral perfusion. Additionally, the frequent need for external ventricular drain (EVD) placement or decompressive craniectomy in these cases necessitates

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careful coordination with the timing of endovascular therapy. In these patients, a short term withholding of therapy, usually 24-72 hours, can be justified to permit physiological stabilization, commencement of ventilatory support, and correction of metabolic derangements [24,28,33].

The further complication comes when adjunctive endovascular procedures, especially stent-assisted coiling (SAC) or flow-diverter, are necessary, and they do not exclude dual antiplatelet therapy (DAPT). Antiplatelet loading in the hyperacute phase is controversial because of higher risk of hemorrhagic complications, particularly when ventriculostomy or other surgeries are required. So, institutions have started to investigate strategies of bridging with intravenous tirofiban or stepwise stenting guidelines, which could permit safer use of SAC without eroding initial securing of aneurysms [29,33,35].

These clinical decision-making subtleties are backed by landmarks trials and meta-analyses. The International Subarachnoid Aneurysm Trial (ISAT) continues to be a landmark study in the same area, as it has shown that endovascular coiling is associated with better survival without major disability one year after experience than surgical clipping in the right cases of ruptured aneurysms [17]. The advantage of timing window, especially early coiling (<72h) leading to lower rebleed and improved neurological outcomes, is further stratified by later observational and prospective studies by Gittins et al. and Consoli et al., especially in stable, good-grade patients [21,22,25,28].

Simultaneously, other global guideline organizations, including the American Heart Association (AHA 2023), European Stroke Organisation, and WFNS, now state that early endovascular intervention in aSAH is cautiously recommended in cases when there are resources and other factors to support the patient. The changing statuses mirror the increasing awareness of the advantages of risk reduction of rebleeding and early neuroprotection startup, should the procedural and perioperational setting be properly managed.

Lastly, with the rising presence of intrasaccular flow disruption devices (e.g., WEB, Contour, Cerus) the early-vs-delayed paradigm is currently redefined. Such, non-DAPT necessitating, devices are especially beneficial in wide-neck bifurcation aneurysms, enabling the treatment of acutely ruptured aneurysms that would formerly have been held over. The introduction of these technologies into early management tracks promises the elimination of delays in treatment and the safety of lesions with anatomical complexity.

8.3 Clinical Implications

This systematic review and meta-analysis have a number of significant clinical and operational implications on the contemporary practice of the management of ruptured intracranial aneurysms using endovascular methods. The strongest evidence, however, is that the data show a preference of early endovascular coiling, especially in the first 72 hours of aneurysmal subarachnoid hemorrhage (aSAH), as a primary form of treatment in patients presenting with good-grade neurological status (WFNS grades I–III).

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Treatment planning wise, these findings serve to highlight that early coiling must be viewed as the default timing option, unless there are contraindications (e.g., hemodynamic instability, poor WFNS grade, or urgent surgery requirement, e.g. hematoma evacuation). Patients who score well in neurological surveys have a reduced chance of rebleeding, lesser mortality, as well as functional recovery, which justifies the need to secure the aneurysm in an all-inclusive neurocritical care strategy. Delays in these cases can unintentionally prolong exposure to the high-risk period of rebleeding with the first 24-48 hours after the rupture [10,20].

Concerning the health system preparedness, institutional infrastructure is critical towards the success of early coiling strategies. To assure 24/7 coverage of trained neurointerventional units, hybrid angiography rooms, and ICU-level care, hospitals should be able to provide coverage of acute cases at all times. In case of lack of such infrastructure, a clearly defined transfer protocol must be in place to make appropriate referrals to competent centers without wasting time. The Timely access to endovascular services (especially in rural or resource-limited areas) can be enhanced by the development of hub-and-spoke networks, which are comparable to the models of stroke thrombolysis [1,5].

The new technology of endovascular devices has also expanded the usage of early coiling to include even anatomically challenging aneurysms. Devices that disrupt intrasaccular flow, including the Woven EndoBridge (WEB), Contour Neurovascular System, and other neck-bridging devices, allow the treatment of wide-neck bifurcation aneurysm without dual antiplatelet therapy (DAPT). This is especially applicable in the case of ruptured aneurysms, in which there is a risk of bleeding during the initiation of DAPT and it can also postpone treatment. These devices provide safe and effective answers to complex ruptured cases by eliminating the necessity of traversing the aneurysm neck with a stent to support the use of these devices in the processes of early intervention [30–32].

The issue of antiplatelet management is still a serious consideration, particularly when the case is stent-assisted coiling (SAC) or flow diverter, in which DAPT is necessary to avoid in-stent thrombosis. In an acutely ruptured aneurysm, the potential of hemorrhagic complications should be weighed against the thromboembolic risks of inadequate platelet inhibition. In response to this, most centers have used bridging solutions that include short-acting glycoprotein IIb/IIIa inhibitors like tirofiban used during the initial coiling, and then delayed DAPT loading when bleeding risks are under control. Instead, a staged procedure, where initial coiling is done without stent, and delayed stenting is done in another session, could also be utilized particularly in wide-neck aneurysms that need long term coverage [3, 29, 33].

Finally, the implications of early coiling are not limited to clinical decision-making but rather to the overarching policy and resource allocation factors. With increasing numbers of aSAH cases in the aging population, health systems need to be proactive in planning the optimization of neurointervention resources, expanding training and standardizing

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protocols to satisfy increasing demand. It should be noted that the collaboration of the teams of neurology, neurosurgery, interventional radiology and critical care is necessary in order to provide the coordination of scientific organization and timely management.

Combined, these clinical implications are a powerful argument to integrate the early coiling interventions into institutional workflows, which are facilitated by suitable infrastructure, device choice protocols, and antiplatelet guidelines to get the highest possible patient outcomes during aneurysmal SAH.

Table 7: Clinical Decision Matrix Outlining Preferred Timing Strategies for Coiling in Ruptured Intracranial Aneurysms Based on WFNS Grade, Procedural Requirements, And Institutional Factors

Clinical Scenario	Preferred Timing	Justification / Notes
WFNS I–III, stable, no antiplatelet required	Early (<72h)	Lower rebleed risk, better mRS outcomes
WFNS IV–V, elevated ICP or unstable vitals	Delayed (≥72h)	Allow stabilization; monitor cerebral perfusion
Wide-neck aneurysm requiring SAC	Delayed or staged	DAPT required; consider tirofiban bridging if early
Wide-neck bifurcation, WEB device available	Early	No DAPT needed; suitable for acutely ruptured aneurysms
After-hours admission, no on-site intervention	As soon as feasible	Initiate transfer protocol or EVD if hydrocephalus

8.4 Limitations

Although this systematic review and meta-analysis has strong points and advantages, such as a narrow research question, a current data synthesis, and the application of the existing meta-analytic techniques, one must admit a number of limitations that can potentially affect the interpretation and external validity of the results.

Primarily, the vast majority of the studies incorporated were retrospective and observational in nature, which, in turn, creates the risk of selection bias, confounding, and heterogeneity in the assignments of treatment. Without randomized control, the choice to coil early or late can have been affected by individual patient variables including a baseline neurological level, clinical stability, comorbidities, or workflow efficiency in the institution. Such confounders are commonly not fully reported and demanding to correct using aggregate data, which can bias observed treatment effects.

Second, the meaning of early versus delayed coiling differed in studies. Though most used a cut-off of less than 72 hours to mean early intervention, some studies used smaller ranges (e.g., less than 24 or 48 hours), others considered delayed intervention to go on as long as 14 days after rupture. This lack of uniform timing criteria introduces moderate heterogeneity into the pooled analysis and complicates direct comparisons across studies. Further, not all studies included granular time stratification (e.g., early within 24h vs 48-72h), which can blur any difference in outcomes in the hyperacute stage.

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Third, the use of adjunctive device was unequally reported throughout the literature used. Stent-assisted coiling (SAC), balloon-assisted coiling (BAC), flow diverter (FD) and devices that disrupt intra-saccal flow (e.g., WEB) have varied timing implications because of the need to use dual antiplatelet therapy or the anatomy of the artery. Nevertheless, in the majority of studies, the outcomes were not stratified with respect to these procedural variables, which limited us in making the decision whether some of the devices prove to be more appropriate in earlier versus late intervention. Consequently, device-specific timing suggestions are theoretical and should be further analyzed in other subgroups in the next studies.

Fourth, short-term outcomes (in-hospital mortality, rebleeding, and modified Rankin Scale at discharge or 30 days) were widely reported but longitudinal functional outcomes after the acute phase were rather limited. Barely one out of five studies offered 6-month or 12-month follow-up data, which limited us to assessing the long-term effect of timing on recovery, cognition, and quality of life. This is especially necessary due to the delayed nature of vasospasm, hydrocephalus, and DCI in reflecting on neurological status, which can only be recognized several weeks later following the episode.

Fifth, there is also no possibility to exclude publication bias and language bias. Even though the funnel plot and the regression test performed by Egger demonstrated the absence of high publication bias, there is a possibility that any negative or neutral effects, especially those of smaller or non-English language studies, were not well represented in the literature reviewed. This can overvalue the advantage of early coiling in the event that good results are selectively reported.

Lastly, there was a lack of prospective data on patient subgroups, including the elderly or patients with an aneurysm of the posterior circulation or patients who were subject to hybrid surgical-endovascular therapies. Consequently, the transfer of the results to such complicated cohorts is unclear.

To circumvent these shortcomings, prospective, multicenter studies using standard definitions of timing, uniform reporting of adjunctive methods, and long term outcome measures are recommended in the future. Research stratified according to WFNS grade, morphology of aneurysm, and the device would further optimize treatment paradigm and allow an individualized course of care. Patient-reported outcomes, neurocognitive assessments and health economic data would also contribute to the greater real-world applicability of future research results and would inform the production of timing-specific clinical practice guidelines.

8.5 Summary Statement

Overall, there is solid evidence in this systematic review and meta-analysis that demonstrates that early endovascular coiling, usually carried out within 72 hours of rupture, and is a clinically beneficial approach to the treatment of ruptured intracranial aneurysm. In several studies conducted on more than 2,300 patients, there were always evidences that early intervention had a considerable decrease in mortality, thinner

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chances of rebleeding, and increase in levels of functional independence at the follow-up. Significantly, these gains were attained in the absence of vasospasm or delayed cerebral ischemia (DCI), thus dispelling previous apprehension of the possible complications of earlier procedural timing.

The results are especially applicable when dealing with patients with good-grade aSAH (WFNS grades I–III), in which early intervention can not only enhance survivability but also allow the timely implementation of vasospasm prophylaxis and intensive neuro-monitoring measures. Delaying coiling in such patients is of only limited value and can potentially expose the patient to the risk of rebleeding the most.

No less significant is the increasing flexibility of the early coiling, which is enabled by the development of the endovascular equipment and the management of periprocedures. Balloon-assisted coiling (BAC), intrasaccular flow disruption devices (e.g. Woven EndoBridge or Luna) and staged stent-assisted approaches have broadened the safety profile of early intervention - even in patients with wide-neck aneurysms, bifurcation geometry, or borderline clinical condition. Moreover, these bridging measures with short acting glycoprotein IIb/IIIa inhibitor like tirofiban are becoming more common to facilitate early treatment to necessitate adjunctive stenting.

Collectively, these innovations make it possible to shift the paradigm to a more aggressive, time-conscious, proactive style of managing aneurysms. With clinical and institutional policies within agreement, early endovascular coiling must be thought of as the default option and not just a convenience, but a more effective therapeutic choice based on existing evidence. The insights are to be used in the formulation of guidelines, resource distribution, and later research to improve the process of individualized treatment in aneurysmal subarachnoid hemorrhage (aSAH).

8.6 Future Directions

Although existing data favors the idea of early endovascular coiling in good-grade aneurysmal subarachnoid hemorrhage (aSAH), there are still a number of avenues that can be developed in the future to make their timing strategies more sophisticated and applicable to a wide range of clinical conditions. Early versus late coiling, in particular, poor-grade patients or when adjunctive methods as stent-assisted coiling (SAC), balloon-assisted coiling (BAC) or flow disruptors are required, is to be definitively compared using prospective and multicenter randomized trials. Such trials must include the use of standardized definitions of timing window (e.g., less than 24h, less than 24 72h, greater than 72h), stratification by WFNS grade, morphology of aneurysms, and type of device.

Second, a clearer evaluation of long-term neurological, cognitive and quality-of-life outcomes after early versus delayed coiling is mandated. Although previous literature has focused on in-hospital mortality or modified Rankin Scale score at discharge, delayed complications, including vasospasm-related infarcts, post-SAH depression, and cognitive impairment have increasingly become recognized as a source of long-term disability.

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Patient-reported outcome measures (PROMs) and neurocognitive testing should be included in the future studies to appreciate the overall effect of timing choices.

Third, the introduction of artificial intelligence (AI) and predictive analytics into the treatment of an aneurysm could be used to optimize when a patient receives treatment on an individual basis. Clinical, radiological, and hemodynamic data integrated into machine learning models may be associated with helping identify patients with the highest likelihood of seeking immediate versus staged intervention, particularly in resource-restricted settings where real-time decision-making is essential.

Finally, research at the health system level should involve how to overcome the logistical challenges to early intervention. These involve efficiency of hub-and-spoke referral systems, the importance of tele-neurointervention and the aspect of quick triage and access to imaging. To provide equitable care access, it will be necessary to increase rural and underserved populations with access to early coiling.

9. CONCLUSION

It has been demonstrated that early endovascular coiling, generally conducted within 72 hours of aneurysmal subarachnoid hemorrhage (aSAH) is a clinically beneficial procedure, which is associated with lower rebleeding rates, decreased mortality, and functional recovery [19–27]. Such advantages are best regularly found in patients who arrive with good-grade neurological state (WFNS grades I3) and where treated in a facility with a well-established neurointerventional experience [9, 20, 24]. Although delayed coiling still can be a viable option in a range of clinical settings (poor-grade aSAH, stent-assisted coiling is required, or referral delays are logistically justified), there is collective support in favor of early intervention when possible and safe [24, 28, 33].

New advances in device technology especially the system of intrasaccular flow disruption, the Woven EndoBridge (WEB), have added to the safety profile of early coiling. Such devices have the potential to treat aneurysms of wide necks without dual antiplatelet therapy, thereby improving the timeliness with which ruptured cases can be treated [3032]. Such technologies, combined with pre-coiling management algorithms that are structured, can be used to make individual decisions based on different institutional resources and patient profiles.

In prospective research, it is proposed that future studies should attempt to prospectively evaluate the timing of coiling in stratified cohorts, including but not limited to WFNS grade and device type, and that outcomes should be compared between adjunctive techniques, including stent-assisted coiling (SAC), balloon-assisted coiling (BAC), flow diverter (FD) and intrasaccular devices across timing windows. Also, future research should focus on long-term clinical, cognitive, and quality-of-life outcomes that would be more informative about patient-centered care. Combined, early coiling is a safe, useful, and increasingly diversified alternative in the treatment of ruptured intracranial aneurysms, with accumulating clinical experience and technology [20-27].

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