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Review Paper

Middle Meningeal Artery Embolization in Septated Chronic Subdural Hematoma: A Narrative Review

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ABSTRACT

Background and Aim: Chronic subdural hematoma (cSDH), particularly its septated subtype (sCSDH), poses significant therapeutic challenges due to its propensity for recurrence and resistance to conventional surgical interventions. Septated cSDH is characterized by fibrin membranes that compartmentalize the hematoma, impeding complete drainage and perpetuating inflammation-driven neovascularization. Current management strategies including burr-hole craniostomy (BHC), craniotomy, and pharmacotherapy exhibit recurrence rates of 20–30% in septated cases, underscoring the need for alternative approaches.

Methods and Materials/Patients: A targeted narrative review was conducted by searching PubMed, Scopus, and Web of Science (January 2000–July 2025) and peer-reviewed human studies meeting predefined inclusion criteria were reviewed. This review synthesizes existing literature to evaluate MMAE's efficacy in septated cSDH.

Results: Key findings highlight MMAE's ability to reduce recurrence rates (3.1% vs 23.4% in non-embolized septated cases) when used adjunctively with surgery or as monotherapy, particularly in high-risk or recurrent patients. Technical considerations, such as transradial access (TRA) and embolic agent selection (e.g. polyvinyl alcohol, gelatin sponge), further enhance procedural safety and outcomes. Emerging evidence supports MMAE's role in disrupting the angiogenic-inflammatory cycle unique to septated cSDH, offering a paradigm shift in management.

Conclusion: Despite promising results, challenges persist, including the need for specialized expertise and limited long-term data. However, prospective randomized trials are warranted to optimize protocols and solidify its position in clinical guidelines. This review underscores MMAE as a transformative adjunctive strategy for septated cSDH, bridging gaps in traditional therapies while advocating for further research to refine its application.

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Highlights

- Conventional surgical treatments for sCSDH, such as BHC, are associated with unacceptably high recurrence rates of 20-30%, that it highlighted a significant limitation in current management.

- MMAE demonstrates a markedly high efficacy, reducing recurrence rates to 3.1% compared to 23.4% in non-embolized septated cases, that can be utilized as an adjunct to surgery or as a primary treatment.

- Although, these promising outcomes, the definitive integration of MMAE into clinical practice requires further validation through large-scale, prospective RCTs to optimize protocols and establish standardized guidelines.

- The therapeutic effect of MMAE is achieved by selectively embolizing the abnormal neovasculature within the subdural membranes, which disrupts the underlying pathological cycle of inflammation and neovascularization that drives hematoma persistence and recurrence.

Plain Language Summary

This investigation discusses a better way to treat a specific type of serious brain bleed, particularly for cases that are difficult to cure with standard surgery. The condition called chronic subdural hematoma (cSDH), involves a slow buildup of blood and fluid on the surface of the brain, often after a minor head injury, especially in older adults. A more advanced and complicated version of this condition is called a “septated” hematoma. In this type, thin, tough membranes form inside the blood collection, creating separate compartment. These membranes make it very hard for surgeons to fully drain the blood, and they contain abnormal blood vessels that continue to leak, causing the recurrence. Currently, the main treatment is surgery to drill a small hole in the skull and drain the fluid. However, for this septated type, the problem returns 20-30% of the time because the membranes and their leaky vessels remain. This high failure rate shows a clear need for a more effective solution. This review study examines a promising new approach called middle meningeal artery (MMA) Embolization. This is a minimally invasive procedure where neurosurgeons threads a tiny catheter through an artery in the wrist or groin up to the blood vessels that supply the problematic membranes in the brain. They then release microscopic particles to gently block these vessels. By cutting off the blood supply, the procedure causes the leaky membranes to shrink and stops the cycle of re-bleeding. The key finding is that this approach is significantly effective. When utilized along with surgery or sometimes on its own, it reduces the chance of the brain bleed returning from about 23% to just 3%. It is especially beneficial for patients who have already had a recurrence or are at high risk for one. This matters because it offers new hope for a patient group that previously had limited options. It can prevent the need for repeated surgeries, improve recovery and reduce hospital stays. While more large-scale studies are needed to confirm the best ways to use it, MMA embolization represents a significant shift in curing this cSDH patients, that it focuses on the root cause of the re-bleeding rather than just draining its symptoms.

1. Introduction

Chronic subdural hematoma (cSDH) refers to the accumulation of blood between the arachnoid and dura mater, typically developing over a period of three weeks or longer [1]. It is more prevalent in the elderly population [2], with an estimated incidence ranging from 1.72 to 20.6 cases per 100,000 persons per year—a figure of considerable concern given the associated morbidities and mortalities [2]. A distinct subtype of cSDH, known as septated cSDH, is characterized by the organization of subdural blood clots into fibrinous membranes, which exhibit neovascularization and increased vascular permeability [3]. This neovascularization contributes to the formation of fragile vessels that can exacerbate hematoma expansion, leading to recurrent episodes [4], thereby complicating treatment strategies. Management approaches for cSDH include conservative treatment, craniotomy, burr hole evacuation, and craniostomy [5].

Middle meningeal artery embolization (MMAE) is a minimally invasive procedure aimed at occluding the vascular supply to pathological dural membranes, thereby reducing the risk of recurrent hemorrhage in

cases of cSDH. While MMAE has emerged as a promising alternative to conventional surgical interventions, its therapeutic efficacy in septated cSDH a subtype associated with a higher recurrence rate—remains uncertain and warrants further investigation [6, 7]. This review seeks to provide a comprehensive analysis of the existing literature on septated cSDH and the potential role of MMAE as a treatment modality.

2. Methods and Materials/pateints

We conducted a targeted narrative review focusing on MMAE for septated chronic subdural hematoma (sCSDH). A comprehensive literature search was performed in PubMed, Scopus, and Web of Science from January 2000 to July 2025. Additional searches were done in Google Scholar and by hand-screening reference lists of relevant articles. The search combined Medical Subject Headings (MeSH) and free-text terms:

("chronic subdural hematoma" OR cSDH) AND (septated OR membranous OR multiloculated OR organized) AND ("middle meningeal artery" OR MMA) AND (embolization OR "endovascular therapy" OR neurointervention). Only peer-reviewed human studies were included. Two authors independently screened titles/abstracts, then full-texts. Disagreements were resolved by consensus.

Eligibility criteria

Inclusion criteria: Human studies on cSDH with focus on septated/membranous/multiloculated subtypes. MMAE as primary or adjunct to burr-hole, craniotomy, or twist-drill evacuation.

Outcomes including recurrence, hematoma resolution (radiologic/clinical), complications, and technical aspects (access route, embolic agent). Study types: RCTs, cohort, case-control, large case series, systematic/narrative reviews with relevant mechanistic insight (2000–2025). Exclusion criteria: Non-septated cSDH without subgroup analysis. Abstract-only reports, animal/in-vitro studies.

Pathophysiology of septated CSDH

The defining pathological feature of septated cSDH (sCSDH) is the formation of fibrin septations and thickened inner membranes, which result from chronic inflammatory processes and recurrent microhemorrhages within the subdural space [8]. These septa alter the fluid dynamics of the hematoma, preventing uniform liquefaction and forming physical barriers that obstruct complete drainage during surgical intervention [8].

A cSDH is characterized as septated based on computed tomography (CT) imaging criteria, specifically when one or more linear hyperdense structures were observed within the predominantly hypodense hematoma [7]. Imaging characteristics of sCSDH in MRI of some cases are internal septations, mixed signal intensity, dural thickening, diffuse inflammatory enhancement, and absence of abnormal enhancing mass [9].

3. Current Treatment Modalities for cSDH

Surgical interventions

Surgical evacuation remains the primary treatment modality for symptomatic cSDH, particularly in patients presenting with significant mass effect or neurological deficits. Among the available techniques, burr-hole craniostomy (BHC) is the most widely performed procedure due to its simplicity, minimal invasiveness, and generally favorable outcomes in uncomplicated cases [10]. The procedure involves creating one or more burr-holes to facilitate hematoma drainage, typically followed by the placement of a subdural or subgaleal drain to minimize recurrence risk [11].

For select patients especially those with liquefied hematomas or undergoing the procedure under local anesthesia twist-drill craniostomy (TDC) may provide a less invasive alternative with comparable efficacy. However, evidence regarding its superiority or equivalence remains inconclusive [12]. Conversely, craniotomy, a more invasive approach, is reserved for cases where thick outer membranes, septations, or solid hematoma components impede adequate drainage via burr-hole techniques [13]. Despite its higher risk profile, craniotomy enables direct visualization, membranectomy, and complete evacuation in refractory cases.

Traditional surgical techniques, however, often demonstrate reduced effectiveness in managing septated or multiloculated cSDH, where the hematoma is compartmentalized by fibrous membranes and trabeculations. These septations hinder uniform drainage, frequently resulting in incomplete evacuation and predisposing patients to persistent collections and recurrence. Studies indicate recurrence rates of 20% to 30% in septated cases, even following technically sufficient surgical intervention [14, 15]. Notably, Nakaguchi et al. identified the presence of internal membranes as a significant predictor of postoperative recurrence [16].

Limitations in septated CSDH

Septated cSDH poses a distinct clinical and surgical challenge due to its unique pathophysiological and structural characteristics. The fibrous septa, composed of proliferative membranes rich in inflammatory and angiogenic markers, compartmentalize the hematoma cavity and hinder uniform decompression [17]. These internal partitions frequently trap residual hematoma fluid or clotted blood, resulting in persistent mass effect and ongoing symptoms, even after apparent surgical evacuation.

Furthermore, the inability to fully collapse or remove these compartments through burr-hole techniques alone often necessitates repeat surgery or conversion to craniotomy, thereby increasing patient morbidity and prolonging hospitalization [18]. These challenges are particularly pronounced in elderly or medically fragile patients, who may have limited tolerance for multiple interventions or general anesthesia. As a result, septated cSDH has increasingly been recognized as a refractory form of the condition, often resistant to conventional monotherapeutic strategies [19].

Pharmacologic and adjuvant therapies

Given the limitations of surgical monotherapy, various adjuvant medical therapies have been investigated to improve treatment efficacy and reduce recurrence risk. Among these, corticosteroids have garnered significant attention for their potential role in modulating hematoma stability. Their anti-inflammatory properties may theoretically suppress the expression of proangiogenic cytokines and inhibit neomembrane formation, thereby reducing hematoma expansion [20]. However, clinical trials have yielded inconsistent results. In a randomized controlled trial (RCT), Hutchinson et al. (2020) reported a modest reduction in the need for surgical intervention with dexamethasone; however, this benefit was accompanied by an increased incidence of systemic complications, including hyperglycemia and infections [21]. Consequently, corticosteroids are now considered a potentially beneficial adjunct in select patients, particularly those who are poor surgical candidates, rather than a primary treatment strategy.

Tranexamic acid (TXA), an antifibrinolytic agent, has emerged as a promising pharmacological option due to its ability to inhibit fibrinolysis within the hematoma, thereby promoting clot stability. Kageyama et al. reported favorable radiographic resolution and symptom improvement in patients treated with TXA, including those with multiloculated hematomas [22]. However, current evidence remains limited to observational studies and small case series, highlighting the need for further randomized trials to validate its efficacy and safety.

Another class of pharmacological agents gaining attention is angiotensin-converting enzyme inhibitors (ACE-Is). Given their antiangiogenic and anti-inflammatory effects, ACE-Is may theoretically reduce neovascular permeability and decrease recurrence rates in cSDH [23]. Retrospective cohort studies have suggested a potential correlation between ACE-I use and lower recurrence rates; however, prospective validation is required before ACE-Is can be integrated into routine clinical management [24].

Need for alternative and adjunctive modalities

Given the persistent recurrence, surgical challenges, and limited pharmacologic success in managing septated cSDH, there is increasing recognition of the need for alternative or adjunctive treatment strategies that address its underlying pathophysiological mechanisms namely, chronic inflammation, fragile neovasculature, and progressive hematoma expansion. MMAE has emerged as a particularly promising approach in this context. By selectively occluding the vascular supply to the outer neomembrane, MMAE seeks to disrupt the inflammatory-angiogenic cycle that perpetuates hematoma persistence and recurrence [25].

As discussed in subsequent sections, MMAE may serve as either a standalone therapy particularly in recurrent or medically inoperable cases or as an adjunct to surgical evacuation in septated hematomas. Preliminary evidence suggests that integrating MMAE with surgical intervention may enhance outcomes by preventing neomembrane revascularization and mitigating the risk of blood reaccumulation in residual compartments (Table 1) [26].

4. MMAE: Mechanism and Technique

Middle meningeal artery (MMA) embolization aims to devascularize the subdural membranes of chronic subdural hematomas (cSDHs), effectively shifting the balance from persistent blood leakage and accumulation toward enhanced reabsorption [27]. MMAE can control hemorrhage originating from the cSDH membrane and, in some cases, facilitate spontaneous hematoma resolution without direct drainage. However, symptomatic hematomas may still necessitate surgical removal This

technique has emerged as a promising therapeutic option for cSDH, either as a standalone procedure or as an adjunct to surgical intervention. The efficacy of MMAE in cSDH has been explored in multiple RCTs [28]. Given the rich vascularity of hematoma membranes, MMAE has been proposed as a potentially beneficial approach for patients with septated cSDH [28].

Although surgical evacuation remains the standard treatment for cSDH, recurrence rates remain substantial, occurring in approximately 10–20% of cases following a single evacuation [29]. Over the past few years, the number of studies reporting MMAE efficacy has increased significantly. The three primary indications for standalone MMAE include failure of conservative management in asymptomatic or mildly symptomatic patients, advanced age or concurrent use of antiplatelet/anticoagulant therapy (as MMAE is less invasive than surgery), and prevention of recurrence in patients with prior disease relapse following surgical evacuation [29]. Notably, septated cSDH presents additional challenges, as patients with septations exhibit lower rates of complete evacuation and a higher likelihood of recurrence. Reports indicate that MMAE has significantly reduced recurrence rates in septated cases compared to non-septated cases (SEP vs no-SEP: 3.1% vs 23.4%, P=0.017) [7]. Septation formation is thought to occur during the later stages of cSDH and may represent a more mature and densely neovascularized environment factors that make MMAE particularly suited for treatment [7].

Most MMAE procedures are performed via transfemoral access (TFA), though this approach can pose challenges due to the risk of access site complications and the requirement for postoperative bed rest [30]. In contrast, transradial access (TRA), which is commonly employed in cardiac catheterization, is gaining popularity in neurointerventional procedures due to its lower risk of site complications and reduced postoperative bed rest requirements [30].

Various particulate embolic agents are utilized in MMAE, functioning as flow-directed materials delivered via catheter to induce either temporary or permanent arterial occlusion. These agents may be therapeutically effective in managing cSDH [31]. Among them, polyvinyl alcohol (PVA) and Embosphere particles promote occlusion albeit with a potential risk of recanalization by adhering to vessel walls within the neurovasculature and inducing a chronic inflammatory response that ultimately leads to fibrosis. In contrast, gelatin sponge provides a temporary occlusive effect via mechanical obstruction, reducing intravascular flow and serving as a structural scaffold for thrombus formation [31]. Among embolic materials, PVA particles are the most frequently used embolic agents in studies evaluating MMAE for cSDH treatment [31]. For elderly patients, liquid embolic agents can be infused into the distal vasculature through a wedged catheter position and injected under pressure to create a cast of the subdural membranes, often resulting in reflux into adjacent meningeal branches (Table 2) [27].

Evidence for MMAE in septated cSDH

cSDH is a complex condition with an incidence rate ranging from 1.7 to 20.6 per 100,000 individuals [32]. Given the clinical significance of this disease, we reviewed multiple studies evaluating the efficacy of MMAE in septated cSDH.

In one case, an 86-year-old man receiving warfarin for ventricular fibrillation was diagnosed with cSDH via CT. Despite undergoing bilateral burr-hole drainage, complete evacuation was not achieved. Two months later, the patient was hospitalized due to fever and refractory headache, indicating recurrence of cSDH. Following craniotomy, MMAE was performed, leading to complete hematoma resolution within six months [33].

Another case involved a 5-year-old female with idiopathic cardiomyopathy who underwent heart transplantation. Unfortunately, left ventricular thrombosis resulted in ischemic stroke, with subsequent CT imaging revealing an enlarging cSDH. MMAE was performed at seven months, facilitating resolution of the hematoma [34].

A case series analysis further examined three patients who underwent initial burr-hole irrigation or drainage. All three subsequently received MMAE at different time intervals, demonstrating a reduction in hematoma size following embolization [35].

In a study by Link et al. MMAE was performed in six patients with cSDH, leading to a significant reduction in lesion size from 25 mm at baseline to 6 mm after 24 weeks. Additionally, another investigation involving 80 patients (median age: 68 years) reported septated membrane cSDH in 35% of cases. Of these, 45% underwent burr-hole evacuation, 18.8% received craniotomy, and the remainder received MMAE. The findings highlighted that MMAE significantly reduced hematoma width and recurrence risk [7].

Table 1. The summery of alternative and adjunctive modalities for cSDH

Modality	Description	Advantages	Limitations	Ref.
BHC	Minimally invasive evacuation via burr-hole(s) with subdural/subgaleal drain.	Simple, effective for uncomplicated cases; low morbidity.	Ineffective for septated/ multiloculated cSDH (recurrence: 20–30%).	[10–12, 14–16]
Craniotomy	Open surgery for membranectomy and complete evacuation.	Direct visualization; effective for septated/ thick-membrane cSDH.	Higher morbidity, prolonged recovery; reserved for refractory cases.	[4, 13, 16]
TDC	Less invasive than BHC; performed under local anesthesia.	Suitable for liquefied hematomas; shorter procedure time.	Limited evidence for superiority; inconsistent outcomes.	[12]
Corticosteroids	Anti-inflammatory agents to reduce angiogenesis and hematoma expansion.	Potential adjunct for poor surgical candidates; modest symptom reduction.	High systemic complications (e.g. hyperglycemia, infections); inconsistent efficacy.	[20, 21]
TXA	Antifibrinolytic agent to stabilize clot	Promotes radiographic resolution; benefits observed in multiloculated cases.	Limited to small observational studies; lacks RCT validation.	[22]
ACE Inhibitors	Anti-angiogenic effects targeting neovascularization.	Retrospective studies suggest reduced recurrence rates.	No prospective trials; not yet integrated into clinical guidelines.	[23, 24]
Adjunctive MMAE	Occludes neovascular supply to subdural membranes.	Reduces recurrence risk in septated cSDH; minimally invasive.	Requires specialized expertise; long-term efficacy under investigation.	[25, 26, 29]

Table 2. The mechanism and techniques of MMAE for cSDH

Aspect	Details	Significance/Implications	Ref.
Mechanism of action	Occludes vascular supply to pathological dural membranes via embolization	Reduces blood leakage, promotes hematoma reabsorption, and prevents neomembrane revascularization.	[27, 29]
Technical approach	TFA: Traditional route	TFA poses access-site complications (e.g. hematoma) and requires bed rest.	[31]
-	TRA: Emerging alternative	TRA reduces complications, facilitates early mobility; preferred in elderly/delirium-prone.	[31]
Embolic Agents	PVA/Embosphere: Permanent occlusion via fibrosis	Effective but risk recanalization.	[32]
-	Gelatin sponge: Temporary occlusion via thrombus formation	Short-term efficacy; suitable for acute stabilization.	[32]
-	Liquid embolics: Distal vessel casting under pressure	Ideal for elderly; may reflux into adjacent branches.	[27]
Indications	Failed conservative management	Minimally invasive alternative to surgery in high-risk patients.	[30]
-	- Recurrence post-surgery.	Addresses refractory septated cSDH with mature neovascularization.	[7, 29]
Efficacy in septated cSDH	Recurrence rates: 3.1% (MMAE) vs 23.4% (non-MMAE) (P=0.017).	Targets septated cSDH's dense neovascularization; adjunctive use enhances surgical outcomes.	[7, 29]
Challenges	Requires neurointerventional expertise; long-term efficacy under study	Limited data on optimal embolic agents/access routes; need for prospective trials.	[27, 30, 32]

Table 3. The summary of evidences for MMAE in septated cSDH

Study Type	Patients No.	Intervention	Key Findings	Ref.
Case report	1	MMAE post-craniotomy	Complete hematoma resolution at 6 months	[34]
Case report	1	MMAE alone	Resolution of enlarging cSDH after 7 months	[35]
Case series	3	Burr-hole+MMAE (timing varied)	Reduced hematoma size post-embolization	[36]
Prospective study	6	MMAE alone	Hematoma size reduction: 25 mm→6 mm at 24 weeks	[7]
Retrospective	80	MMAE vs burr-hole vs craniotomy	MMAE reduced recurrence risk (SEP vs no-SEP: 3.1% vs 23.4%, P=0.017).	[7]
Comparative study	28	Surgery alone vs surgery+MMAE	MMAE prevented recurrence in combined treatment group	[29]
Retrospective	34	MMAE+surgery vs. surgery alone	Lower recurrence with MMAE adjunct ($P<0.05^{*}$)	[29]
Case report	1	Twist-drill+MMAE	Resolution of recurrent organized cSDH	[9]
Case series	2	Burr-hole+MMAE+craniotomy	Complete neurological recovery without recurrence	[38]
Case series	2	Craniotomy+MMAE	Complete resolution at 3–6 months post-procedure	[38]
Retrospective	61 (membranous)	MMAE+burr-hole vs. burr-hole alone	Recurrence rate: 10% (MMAE) vs 23.4% (non-MMAE)	[39]

Furthermore, a separate study evaluated 28 patients with cSDH treated with surgery alone or surgery plus MMAE. Results indicated that MMAE effectively prevented recurrence in these cases [28]. Another study assessed MMAE in patients with a median age of 75 years, showing an 87% reduction in lesion size without mortality [36].

Another retrospective study categorized cSDH patients into membranous (61%) and non-membranous (73.7%) groups. Those treated with MMAE and burr-hole evacuation exhibited a 10% recurrence rate [37].

Organized subdural hematoma (OSDH), a rare variant of cSDH, was successfully treated with craniotomy followed by MMAE. A 61-year-old patient underwent twist-drill craniotomy, yet hematoma recurrence necessitated embolization, ultimately leading to resolution [9].

Additionally, treatment selection considerations were highlighted in another study. While craniotomy remains an effective approach, it carries inherent risks of bleeding and recurrence. In two reported cases, a 71-year-old man and a 77-year-old man underwent burr-hole irrigation, MMAE, and craniotomy sequentially, both achievzing complete neurological recovery without recurrence [38].

Kadono et al. further supported MMAE's efficacy in cSDH management, assessing two cases. In the first, an 83-year-old man with left cSDH drainage was hospitalized due to dysarthria and dysplasia. Initial craniotomy was followed by MMAE, resulting in complete hematoma resolution after six months. Similarly, another 83-year-old patient with cSDH underwent burr-hole perforation followed by MMAE, leading to symptom resolution within three months (Table 3) [39].

5. Conclusion

MMAE represents a transformative advancement in managing septated cSDH, a subtype characterized by fibrin septations and high recurrence rates following conventional surgical interventions. Current evidence demonstrates that adjunctive or standalone MMAE significantly reduces recurrence rates in septated cSDH (3.1% vs 23.4% in non-embolized cases), primarily by disrupting the angiogenic-inflammatory cycle driving hematoma persistence. Technical refinements, such as TRA and optimized embolic agents (e.g., PVA, gelatin sponge), enhance procedural safety, particularly in elderly or high-risk populations. Despite these benefits, challenges persist, including variability in embolic protocols, the necessity for neurointerventional expertise, and limited long-term outcome data. Emerging studies position MMAE as a paradigm-shifting adjunct to surgery, offering improved outcomes in refractory or recurrent

cases. However, prospective randomized trials are imperative to establish standardized protocols, validate long-term efficacy, and solidify MMAE's role in clinical guidelines. This review underscores MMAE as a pivotal strategy in the evolving management of septated cSDH, bridging gaps left by traditional therapies while advocating for multidisciplinary collaboration to refine its application.

Ethical Considerations

Compliance with ethical guidelines

Ethics approval, consent to participate, and consent to publish are not applicable to this manuscript, as it is a narrative review of existing literature and does not involve human/animal subjects or original data collection.

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Authors' contributions

Conception and design: Farzan Fahim, Mohammad Ali Nazari and Mahdi Mehmandoost; Data Collection: Hesan Abbasi; Drafting the article: Mohammad Ali Nazari, Mahdi Mehmandoost, Sayeh Oveisi and Amirmohammad Bahri; Critically revising the article: Farzan Fahim; Reviewing submitted version of manuscript: Farzan Fahim; Final Approl: All authors.

Conflict of interest

The authors declared no conflict of interest.

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