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ORIGINAL ARTICLE

Use of Middle Meningeal Artery Embolization in Treatment of Chronic Subdural Hematoma

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Abstract

Introduction: Chronic subdural hematoma (cSDH) is a common neurosurgical condition in the elderly, frequently associated with trauma and antithrombotic therapy. Conventional surgical evacuation is effective but carries a significant risk of recurrence. Middle meningeal artery (MMA) embolization has recently emerged as a minimally invasive technique targeting the underlying vascular pathology of cSDH. This study aimed to assess the safety and efficacy of MMA embolization in the management of chronic subdural hematoma. **Materials and Methods:** This prospective observational study included 36 patients with radiologically confirmed cSDH who underwent MMA embolization, with or without surgical evacuation. Written informed consent was obtained and institutional ethical approval was secured. Clinical data, imaging findings, Glasgow Coma Scale (GCS), hematoma volume, recurrence, and need for re-surgery were recorded. Serial CT/MRI scans were performed postoperatively and during follow-up. **Results:** The mean age was 66.64 ± 13.10 years, with male predominance (88.89%). Headache was the most common presenting symptom (33.33%). Burr-hole evacuation was performed in 69.44% and craniotomy in 30.56%. Mean GCS improved significantly from 13.94 ± 1.37 on admission to 14.89 ± 0.32 at discharge ($p = 0.0001$). Subdural hematoma volume showed progressive and statistically significant reduction on both sides over follow-up (ANOVA $p < 0.001$). **Conclusion:** MMA embolization is a safe and effective adjunct in the treatment of chronic subdural hematoma, resulting in significant neurological improvement, sustained hematoma reduction, and low recurrence rates. It represents a promising minimally invasive strategy addressing the underlying pathophysiology of cSDH.

Keywords: Chronic subdural hematoma, Middle meningeal artery embolization, Hematoma recurrence, Glasgow Coma Scale, Minimally invasive neurosurgery

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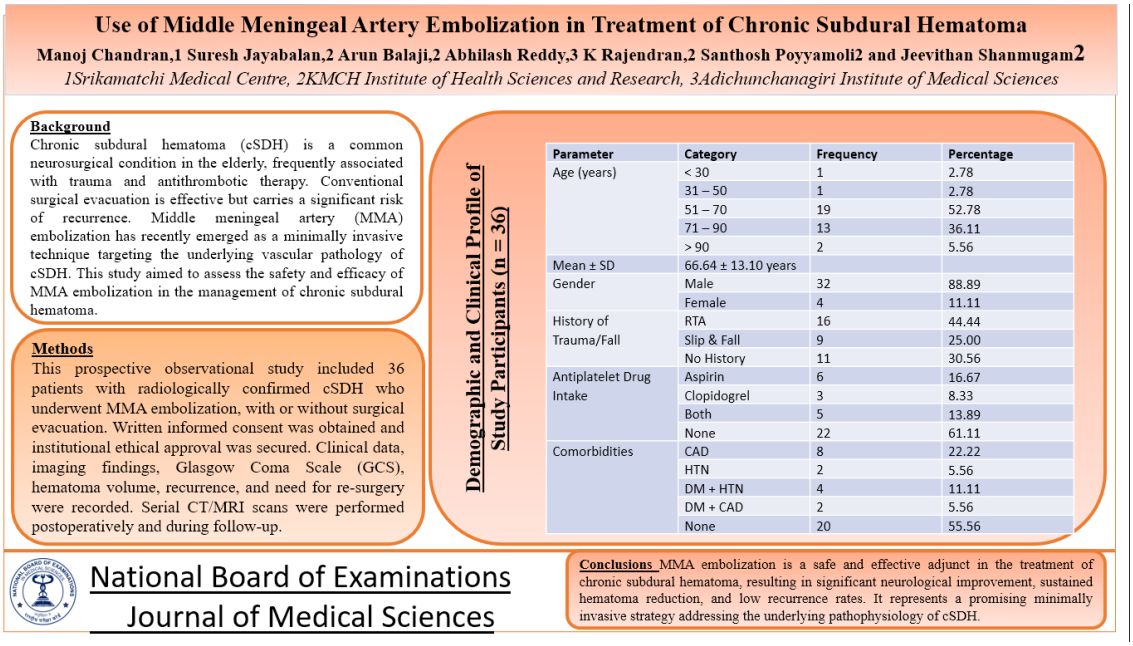
Graphical Abstract



Introduction

The Chronic subdural hematoma (cSDH) is one of the commonest neurosurgical diseases [1]. Its incidence is rising among the aging population and with the increasing use of antiplatelet and anticoagulant medications. The annual incidence of cSDH ranges from 1.7 to 20.6 per 100,000 across the studies. Though the number of cases has been increasing for decades, the large-scale population-based studies are not in significant numbers. This increase is attributed to the higher frequency of falls, brain atrophy, and widespread use of antithrombotic agents. Men have a greater risk of developing cSDH than women. The age-related increase in incidence is combined with a growing elderly population and it poses a major challenge for neurosurgical treatment practices, as the large proportion of these cases require operative management [1].

Spontaneous resolution of cSDH is found to be rare and it has been reported in patients with thrombotic thrombocytopenic purpura primarily [2]. The craniotomy with drainage or Burr-hole irrigation remains as the gold standard treatment for symptomatic cases; But the recurrence occurs in 5% to 30% of the operated patients [3]. Symptomatic recurrences often require, re-surgery, which may not be successful in coagulopathic, elderly, or anticoagulated patients with multiple comorbidities [4]. Various medical therapies aimed at modulating the angiogenic pathways and inflammatory pathways in cSDH have proved limited success [5].

Since the surgical evacuation alone does not address the underlying pathophysiologic mechanism of cSDH, recurrent hematomas are thought to arise and the formation of fragile capillaries within the vascularized neomembrane may encapsulates the hematoma [6]. Middle meningeal artery (MMA) embolization is shown to be a promising minimally invasive technique, either as an alternative or adjunct to surgery, for treating the non-acute subdural hematomas (NASHs). Earlier reports have showed the favourable

outcomes, suggesting the superior safety and efficacy when compared with the conventional surgery [7]. The main advantage of the MMA embolization is to target the underlying disease pathology by devascularizing the immature capillary network of the neomembrane. Also, it reduces the cycles of rebleeding, micro-hemorrhage, and hematoma expansion over the period of time [8,9].

Recent researches have explored MMA embolization in patients with recurrent hematomas or those who cannot discontinue the anticoagulant therapy [10]. Preliminary investigations have showed its efficacy and safety, both as a standalone procedure and also in combination with the surgical evacuation [11]. Based on this background, the current research was done to assess the use of embolization of middle meningeal artery in the treatment of chronic subdural hematoma and to evaluate its long-term efficacy and safety in achieving permanent resolution of cSDH.

Materials and Methods

This prospective observational study was conducted in a tertiary care centre after getting the approval from the Institutional Ethics Committee. It strictly adhered to the principles laid down in the Declaration of Helsinki. The written informed consent was obtained from all the study participants or their legally authorized representatives (LARs) prior to including them in the study. Each participants were informed in detail about the embolization procedure, nature of the study, possible benefits and risks, and the requirement for follow-up of imaging techniques. Confidentiality of all medical and personal data were maintained throughout the study period. The participants and legally authorized representatives were also informed that if the participant, on regaining the full consciousness, declines to the participation later, the individual can be excluded from the study.

The study participants included a total of 36 patients diagnosed with chronic subdural hematoma (cSDH) who had undergone middle meningeal artery (MMA) embolization at the Department of Neurosurgery. All the patients were diagnosed based on the radiological confirmation by computed tomography (CT) or magnetic resonance imaging (MRI) of the brain and the characteristic clinical findings. Patients with intracerebral hemorrhage, coagulopathies, acute subdural hematoma, or those who were hemodynamically unstable were excluded from the study. Demographic details, history of trauma or fall, comorbid conditions, clinical presentation, and use of antiplatelet or anticoagulant medications were recorded for each case.

Middle meningeal artery embolization was conducted under local or general anaesthesia by an experienced neuro interventionist. This procedure involved the access of femoral artery using the Seldinger technique, followed by the selective catheterization of the external carotid artery and the identification of the middle meningeal artery. The n-butyl cyanoacrylate (NBCA), polyvinyl alcohol (PVA) particles, or Onyx Embolization were used as an embolic agent depending on operator preference and blood vessel anatomy. The main objective was to perform the complete occlusion of the distal arteries supplying the hematoma membrane, at the same time preserving the normal meningeal perfusion. During the post-embolization period, the participants

were monitored for any procedure-related complications or neurological changes.

For the patients presenting with significant mass effect or the neurological problems, craniotomy or burrhole evacuation was performed, prior to or in combination with Middle meningeal artery embolization. The postoperative management included the avoidance of the unrequired anticoagulation, optimization of coagulation parameters, blood pressure and neurological observation. All the patients had undergone the follow-up neuroimaging (MRI or CT) in the immediate post-operative period, at one month, three months, and six months to evaluate the hematoma resolution and detect the recurrence. Glasgow Coma Scale (GCS) was used to assess the clinical outcomes at the admission and discharge.

Radiological investigations included the measurement of volume of subdural hematoma (SDH) using the standard formula (length × height × width x 0.5). The difference in subdural hematoma volume between the preoperative, immediate postoperative, and follow-up scans was recorded for both the cerebral hemispheres. Any reaccumulation of hematoma or recurrence causing the need for re-surgery were also noted. Adverse events such as new neurological deficits, rebleeding, or ischemic complications, were monitored with care.

All data were entered in Microsoft Excel and were analysed using version 27.0, Statistical Package for the Social Sciences (SPSS). The categorical variables were expressed as percentages and frequencies. The quantitative variables like age, GCS and hematoma volume were expressed as mean ± standard deviation (SD). Comparison of continuous variables between pre- and postoperative parameters were done using the paired t-tests. The changes in hematoma volume across the different time intervals were analysed using one-way analysis of variance (ANOVA). A p-value < 0.05 was considered as statistically significant.

Results

The study population were mainly the elderly males, with an average age of 66.64 ± 13.10 years, showing that chronic subdural hematoma affects the elderly individuals. Most of them (52.78%) were between the age group 51 and 70 years, and 36.11% were between the age group 71 and 90 years, underscoring age as a major risk factor. 88.89% of the cases, were males, suggesting a higher predisposition in them, possibly due to the anticoagulant usage or increased trauma exposure. A history of trauma was found in 69.44% of the study participants, mostly due to road traffic accidents (44.44%) and slip and fall incidents (25.00%) while the 30.56% of them had no injury or definite history, suggesting that even unnoticed or minor trauma may precipitate SDH in the susceptible individuals. Considering the comorbidities, 44.44% of the participants had associated systemic illnesses such as coronary artery disease (22.22%), diabetes with hypertension (11.11%), or hypertension alone (5.56%). 38.89% were notably on antiplatelet therapy like aspirin, reflecting the influence of hematologic and vascular risk factors (Table 1).

Table 1. Demographic and Clinical Profile of Study Participants (n = 36)

Parameter	Category	Frequency	Percentage
Age (years)	< 30	1	2.78
	31 – 50	1	2.78
	51 – 70	19	52.78
	71 – 90	13	36.11
	> 90	2	5.56
Mean ± SD	66.64 ± 13.10 years		
Gender	Male	32	88.89
	Female	4	11.11
History of Trauma/Fall	RTA	16	44.44
	Slip & Fall	9	25.00
	No History	11	30.56
Antiplatelet Drug Intake	Aspirin	6	16.67
	Clopidogrel	3	8.33
	Both	5	13.89
	None	22	61.11
Comorbidities	CAD	8	22.22
	HTN	2	5.56
	DM + HTN	4	11.11
	DM + CAD	2	5.56
	None	20	55.56

The commonest presenting symptoms in this cohort were headache (33.33%), followed by unilateral limb weakness (19.44%), decreased physical activity (13.89%), and or giddiness or gait disturbances (13.89%), suggesting the diverse and subtle neurological manifestations of cSDH. Radiological imaging revealed that left-sided hematomas were found to be the most frequent (52.78%), followed by bilateral involvement (27.78%) and right-sided lesions (19.44%), which suggest a left-sided predominance. The surgical intervention, burrhole evacuation was performed in 69.44% of the participants, while craniotomy was the necessary intervention in the rest 30.56%, which indicates that minimally invasive techniques were the effective and preferred in most cases. Postoperatively, recurrences were observed in 13.89%, and re-surgery was required in 5.56% of the cases, which are within the acceptable clinical limits for this procedure (Table 2).

Table 2. Clinical Presentation, Radiological Findings, Type of Surgery, and Neurological Outcome

Clinical Symptoms	Frequency	Percentage
Presenting Symptoms and Neurological Status		
Headache	12	33.33
Right UL/LL Weakness	7	19.44

Decreased Physical Activity	5	13.89
Giddiness ± Difficulty Walking	5	13.89
Altered Speech / Headache + Vomiting	4	11.11
Others	3	8.33
CT/MRI findings		
B/L Chronic SDH	10	27.78
Left Chronic SDH	19	52.78
Right Chronic SDH	7	19.44
Type of surgery done		
Burrhole	25	69.44
Craniotomy	11	30.56
Distribution of Recurrence and Re-surgery		
Recurrence	5	13.89
Re-surgery	2	5.56

Serial volumetric assessment proved a statistically significant and progressive reduction in the size of subdural hematoma over time following the embolization of middle meningeal artery. On the right side, the average hematoma volume decreased from 107.40 ± 19.20 cc preoperatively to 21.33 ± 10.30 cc in the immediate postoperative period and, 13.11 ± 13.20 cc after one month, and further to 8.55 ± 9.25 cc after six months. Similarly, the left-sided hematomas reduced from 99.40 ± 20.59 cc preoperatively to 23.11 ± 13.86 cc postoperatively, 12.89 ± 10.64 cc at one month, and 7.54 ± 7.69 cc at six months. The ANOVA test ($p < 0.001$) proved that these reductions were statistically significant on both the sides. The results clearly suggests that the sustained radiological improvement, with most patients achieving nearly complete resolution of the hematoma within the period of six months, reinforcing the efficiency of MMA embolization in causing long-term hematoma resorption and to prevent recurrence (Table 3).

Table 3. Serial Changes in Subdural Hematoma Volume

Time	Right(n=19)		Left(n=28)	
	Mean	SD	Mean	SD
Pre op	107.4	19.20	99.4	20.59
Immediate post op	21.33	10.30	23.11	13.86
After 1 month	13.11	13.20	12.89	10.64
After 6 month	8.55	9.25	7.54	7.69
ANOVA	**P<0.001**	**P<0.001**	**P<0.001**	**P<0.001**

The bar chart compares the Glasgow Coma Scale (GCS) scores before and after the treatment shows a significant improvement in neurological function. The mean Glasgow Coma Scale scores increased from 13.94 ± 1.37 on admission to 14.89 ± 0.32 on discharge (p = 0.0001), which indicates the statistically significant recovery of cognitive function or consciousness following the middle meningeal artery embolization and surgical intervention (Figure 1).

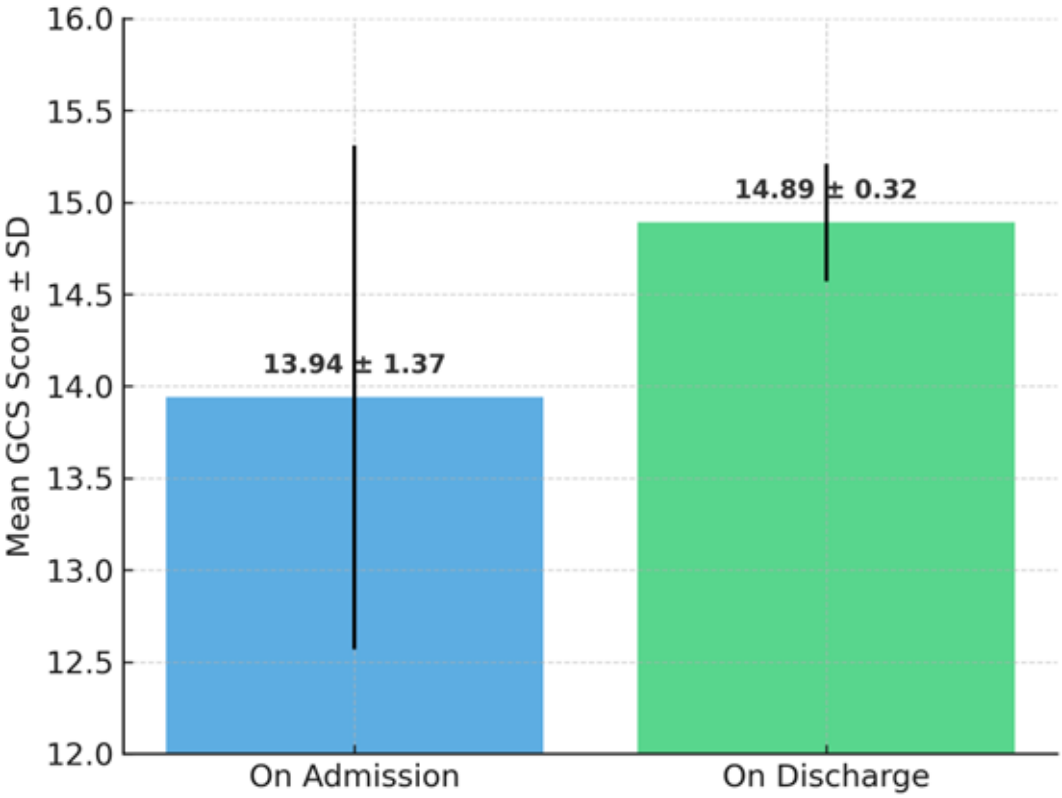


Figure 1. Comparison of GCS on Admission and Discharge (p = 0.0001).

Discussion

In this study, the chronic subdural hematoma (cSDH) patients (N= 36) who had undergone middle meningeal artery (MMA) embolization, more than half of them (53%) were aged between 51–70 years, with an average age of 66.64 years. Ban et al. (2018) showed that a similar age distribution (> 65 years), correlating with our findings [12]. cSDH is mainly a disease of the elderly, which is attributed to stretching of bridging veins, brain atrophy, and a fragile neomembrane prone to re-bleeding [13]. With the advancing age and increasing use of antiplatelet or anticoagulant therapy, this incidence continues to rise, and also, nearly 60,000 new cases are projected annually [14].

A marked male predominance (89%) was observed in the literature search, similar to the findings of Ban et al. (2018) and Peter Kan et al. (2021), who emphasized the occurrence in 60% and 71% of male patients, respectively [12,15]. Men are more likely to sustain trauma and have increased rates of vascular comorbidities which requires antithrombotic therapy, predisposing them

to cSDH. In our research, fourteen patients were on anticoagulant or antiplatelet medication. Pre-injury usage of these drugs has been associated with enlargement or delayed bleeding of the intracranial hematomas, raising both the morbidity and mortality rates [13].

Headache (33%) was the commonest presenting complaint, followed by the weakness in the limb, giddiness, and reduced activity. These findings showcase the non-specific neurological manifestations described in the previous studies [12,13,15]. Such symptoms are often subtle, and an early neuroimaging is needed to prevent neurological deterioration.

MMA embolization has been identified as an effective alternative or adjunct to surgery for cSDH, especially in patients with high surgical recurrence or risk. Its mechanism is physiological as it targets the pathological neo membrane, supplied by the fragile branches of the MMA. Thereby it interrupts the cycles of micro-haemorrhage and exudation responsible for the persistence of hematoma [14,16]. These studies demonstrate the consistent results like favourable outcomes and low recurrence rates. The above technique typically utilises the microparticle embolic drugs, though liquid embolisates such as SQUID or Onyx, which may provide deeper penetration and more durable occlusion; But still the complete comparative evidence is lacking.

The safety profile of middle meningeal artery embolization in the current study was good, with no major adverse effects, mimicking the results of Link et al. [17] and Ban et al. [12], which demonstrated, nil procedural complications. A meta-analysis by Srivatsan et al. [18] further emphasized the lesser complication rates (2%) in this, when compared to the conventional surgery (4%). In our series, burr-hole evacuation was done in 69% and craniotomy was performed in 31% of cases. The mean volume of subdural hematoma was reduced significantly postoperatively ($p < 0.0001$) and it also decreased at one month and six-month follow-ups. Recurrence was seen in 5 patients (13.9%), with 2 of them requiring re-surgery, which is well below the recurrence rate of 28%, usually reported after the surgery alone [19-21]. By six months, all the patients showed complete resolution of hematoma, except one, indicating durable benefit of the procedure.

The success of middle meningeal artery embolization rests in revascularizing the inflammatory membrane and preventing the angiogenic leakage, which prevents further accumulation. This also allows slow resorption of the existing clot and promotes long-term healing. The effectiveness of this approach has been validated by several clinical series showing sustained hematoma regression and reduced need for repeat procedures [17-20].

Ongoing randomized controlled trials are expected to strengthen the evidence base. The SQUID Trial (STEM) is evaluating the safety and efficacy of SQUID as an embolic material [22], while the EMBOLIZE Trial is assessing Onyx for subacute and chronic SDH [23]. Both are designed to compare conventional management with and without MMA embolization and will help clarify patient selection criteria and optimal timing [24].

Conclusion

This study demonstrated that MMA embolization facilitates resolution, prevents reaccumulation of CSDH and is more effective to be used in addition to

conventional treatment without increasing treatment related complications. It can be considered as a definitive treatment option for CSDH among older age group individuals especially those with multiple comorbids. It may be a safe and efficacious minimally invasive procedure that can be utilised in CSDH patients at a higher risk of recurrence. Favorable outcomes were obtained by performing embolization at an early stage when signs of recurrence appeared.

Statements and Declarations

Conflicts of interest

The authors declare that they do not have conflict of interest.

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