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Middle Meningeal Artery Embolization for Recurrent Chronic Subdural Hematoma

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Objective : Repeating surgical treatment remains the main option for recurrent chronic subdural hematoma, but a second recurrence frequently occurs. We employed middle meningeal artery embolization as an alternative treatment for recurrent hematoma. This study aimed to evaluate the effect and safety of middle meningeal artery embolization compared with conventional retreatment.

Methods : We retrospectively reviewed 1162 patients who underwent management for chronic subdural hematoma between May 1998 and March 2025 and included 142 patients with recurrent hematoma (middle meningeal artery embolization in 46 and conventional retreatment in 96) in this study. The primary outcome was second recurrence, defined as a composite of imaging (recurrent or residual hematoma >10 mm in thickness) and clinical (development or aggravation of symptoms, or second re-operation) events. Secondary outcomes included complications (any adverse events or death) and neurological recovery (return of the modified Rankin scale score to the level before initial hematoma development). Outcomes during treatment and 6-month follow-up were compared between the two study groups using logistic regression analysis, adjusted for variables showing baseline group differences with a *p*-value <0.2.

Results : The second recurrence rate was significantly lower in patients receiving middle meningeal artery embolization than in those receiving conventional retreatment (1/46 [2.2%] vs. 32/96 [33.3%]; adjusted odds ratio [OR], 0.056; 95% confidence interval [CI], 0.003–0.164; *p*=0.001). Complication rates did not differ significantly (1/46 [2.2%] vs. 10/96 [10.4%]; adjusted OR, 0.203; 95% CI, 0.019–1.221; *p*=0.103), but neurological recovery was more frequent in patients receiving middle meningeal artery embolization (32/46 [69.6%] vs. 46/96 [47.9%]; adjusted OR, 3.147; 95% CI, 1.198–8.268; *p*=0.020).

Conclusion : Middle meningeal artery embolization for recurrent chronic subdural hematoma prevented second recurrence and improved neurological recovery compared with conventional retreatment, without increasing the complication rate. These findings suggest that middle meningeal artery embolization could be considered an effective and safe retreatment option for recurrent chronic subdural hematoma.

Key Words : Chronic subdural hematoma · Recurrence · Therapeutic embolization · Meningeal arteries.

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INTRODUCTION

Middle meningeal artery embolization for chronic subdural hematoma interrupts the pathologic neovascular supply to the outer membrane which leads to recurrent exudation and microbleeding, thereby promoting resolution of chronic subdural hematoma[1,9]. Over recent years, middle meningeal artery embolization has been increasingly employed as an alternative treatment for chronic subdural hematoma, and several randomized controlled trials have confirmed its efficacy and safety in reducing the risk of treatment failure[2,5,12,17]. In South Korea, middle meningeal artery embolization for chronic subdural hematoma began to be used early in clinical practice, but the National Health Insurance Review and Assessment Service restricted its use to cases of recurrent chronic subdural hematoma in 2016.

Chronic subdural hematoma can recur after initial treatment. Conventional retreatment for recurrent chronic subdural hematoma typically involves close observation and re-operation for cases in which the hematoma increases in volume on serial imaging and causes to mass effect or neurological symptoms[3,4]. Following the policy of the National Health Insurance Review and Assessment Service, our institution revised the protocol for middle meningeal artery embolization in the chronic subdural hematoma; the embolization is used only in recurrent cases after initial treatment, but applied early before symptoms occurs without more follow-up, once hematoma re-accumulation has been confirmed. In the present study, we summarized the results of patients with recurrent chronic subdural hematoma who were managed under this protocol, and evaluated the effect and safety of middle meningeal artery embolization compared with the conventional retreatment.

MATERIALS AND METHODS

This retrospective study was approved by the Institutional Review Board of Bundang Jesaeng Hospital (IRB No. 2025-12-003). The requirement to obtain written informed consent to participate in this study was waived. All patients with chronic subdural hematoma in whom hematoma re-accumulation was detected after initial treatment were screened for eligibility. We excluded patients who 1) had recurrent hematoma that remained 10 mm or less in thickness without any mass effect (cortical flattening or midline shift) up to 6 months after initial treatment, 2) underwent craniotomy on the affected side as initial treatment, which could cause damage to the middle meningeal artery, 3) had underlying brain conditions (vascular lesions, brain tumor, arachnoid cyst, spontaneous intracranial hypotension, or ventriculo-peritoneal shunt), and 4) were lost to regular follow-up after retreatment.

Between May 1998 and March 2025, 1162 patients with chronic subdural hematoma underwent hematoma removal. Of them, hematoma re-accumulation after initial treatment was observed in 212, who were screened for eligibility. According to inclusion and exclusion criteria, 70 patients were excluded: spontaneous hematoma absorption or residual hematoma with 10 mm or less in thickness during follow-up in 25, craniotomy as initial treatment in 34, arachnoid cyst in two, ventriculo-peritoneal shunt in three, spontaneous intracranial hypotension in two, and follow-up loss in four. Finally, a total of 142 patients were included in this study : 46 (32.4%) underwent middle meningeal artery embolization according to the revised protocol and 96 (67.6%) were treated with conventional retreatment.

We collected demographic, clinical, laboratory, radiologic, and treatment-related data of patients. Clinical data included modified Rankin scale score, presence of symptoms, and medical history. Laboratory findings included platelet count and coagulation test results. Radiological findings included the presence of brain atrophy (widely dilated sulci and subdural space)[15], hematoma side, Nakaguchi classification (homogenous, laminar, separated, or trabecular type)[14], hematoma width, and midline shift. Treatment-related data included the interval between initial treatment and retreatment and the surgical method for hematoma removal.

Conventional treatment

When hematoma re-accumulation was observed on follow-up computed tomography (CT) after initial hematoma removal, close follow-up was recommended unless the recurrent hematoma had mass effect or clinical symptoms (headache or neurological deficits). However, if the hematoma increased on serial CT images and clinical symptoms eventually developed during close follow-up, hematoma removal including burr-hole drainage or craniotomy was performed again. The technique and choice of surgical method were conventional and determined by the characteristics of the recurrent hematoma. Thrombocy-

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topenia or coagulopathy was corrected using proper methods before hematoma removal. Antiplatelet or anticoagulation therapy for underlying diseases was also discontinued and reversed. Unless patients had a high risk for thromboembolic events, resumption of antiplatelet or anticoagulation therapy was delayed for a sufficient period (usually more than one month) to prevent the second recurrence. Clinical and radiologic follow-ups with CT scans were performed at 1, 3, and 6 months after hematoma removal. The follow-up schedule was adjusted on the basis of clinical status and radiologic findings.

Middle meningeal artery embolization

After the treatment protocol for recurrent chronic subdural hematoma was changed in 2016, middle meningeal artery embolization was primarily applied regardless of symptom development, once hematoma re-accumulation greater than 10 mm in thickness was identified on CT following initial treatment. The embolization was performed without systemic heparinization under local anesthesia, following standard middle meningeal artery embolization method (Fig. 1).[1] A 5 F guiding catheter was placed in the proximal external carotid artery or distal common carotid artery, and the middle meningeal artery was selected with a microcatheter (Excelsior SL-10; Stryker Neurovascular, Fremont, CA, USA) and a guidewire (Synchro-14; Stryker Neurovascular). Before embolization, selective angiography through the microcatheter was performed to select target branches of middle meningeal artery and to detect potentially dangerous collateral vessels. Middle meningeal branches supplying blood to convexity dura were selected as the target for embolization. If no collaterals were observed, target branches were embolized with polyvinyl alcohol particles (Contour 150–250 μm; Boston Scientific, Marlborough, MA, USA). In cases

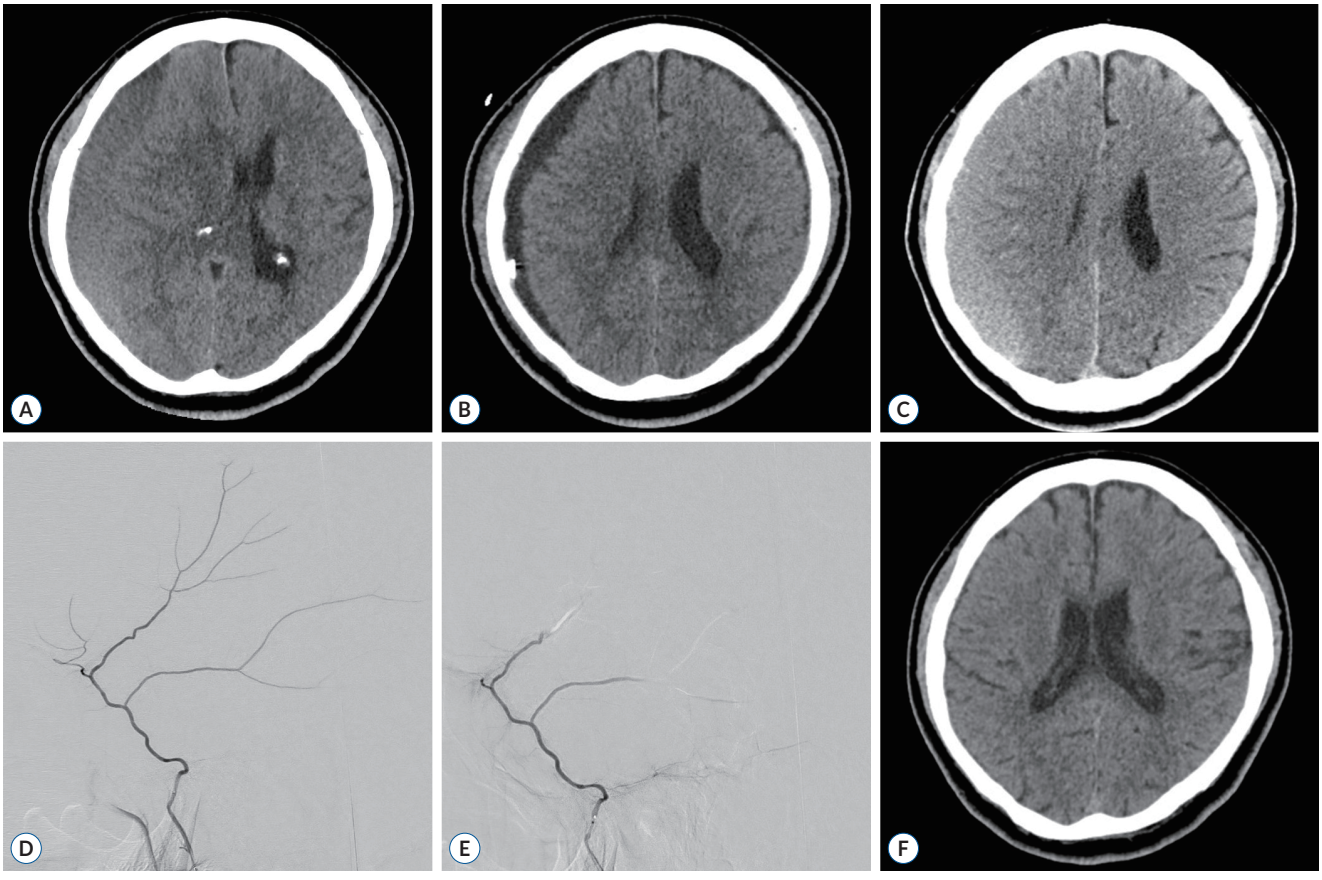

Fig. 1. Images in a 72-year-old man receiving middle meningeal artery embolization for recurrent chronic subdural hematoma. Brain computed tomography (CT) scan (A) shows chronic subdural hematoma occupying right frontotemporoparietal area, which was successfully removed by burr-hole drainage (B). Follow-up brain CT scan (C) 1 month after discharge shows an asymptomatic recurrent hematoma with a maximum width of 20.5 mm. Target branches of middle meningeal artery are confirmed with selective angiography using microcatheter (D) and embolized with polyvinyl alcohol particles (E). Brain CT scan (F) 3 months after the embolization shows complete resolution of hematoma.

with dangerous collateral vessels, the embolization was performed after the microcatheter was advanced more distally or collateral vessels were occluded with coils. When flow stasis of the middle meningeal artery was confirmed, the procedure was concluded. The procedure was considered successful when all target branches of middle meningeal artery were embolized without procedural complications.

Asymptomatic patients were discharged on the same day after embolization, whereas symptomatic patients additionally underwent hematoma removal for rapid symptom relief and were discharged after clinical conditions were improved. Antiplatelet or anticoagulation therapy was not reversed and was maintained without discontinuation throughout treatment and follow-up. Thrombocytopenia or coagulopathy was corrected only in patients who underwent hematoma removal. Clinical and radiological follow-up was conducted in the same manner as conventional treatment.

Outcomes

The primary outcome was second recurrence, defined as a composite of imaging (recurrent or residual hematoma larger than 10 mm in thickness at 6 months after retreatment for recurrent hematoma) and clinical (development or aggravation of symptoms, or second re-operation within 6 months after retreatment) events[1,5]. Secondary outcomes included complications (any adverse events or death during treatment and 6-month follow-up period) and neurological recovery (return of the modified Rankin scale score within 6 months to the score before the initial development of chronic subdural hematoma).

Statistical analysis

The Wilcoxon rank-sum test was used for continuous variables, and the chi-squared test or Fisher's exact test was used for categorical variables in comparisons of baseline characteristics. Outcomes were compared between patients receiving middle meningeal artery embolization and conventional retreatment using logistic regression analysis. The comparison was adjusted for variables showing a baseline group difference with a p-value of <0.2 and provided with an adjusted odds ratio (OR) and 95% confidence interval (CI). Penalized likelihood estimation was applied in logistic regression to address zero or rare events. Surgeons were included as a random effect in the logistic model to account for heterogeneity among the surgeons and data structure in which study subjects were clustered within each surgeon.

We performed propensity score matched analysis in addition to principal analysis using the full cohort. This study had a 2×2 factorial trial design consisting of middle meningeal artery embolization and hematoma removal, and thus we also performed a factorial design analysis to further evaluate the individual efficacy of middle meningeal artery embolization and hematoma removal and interaction between the two treatments[13]. Detailed statistical methods of these analyses are described in the Supplementary Materials. Because the principal analysis in this study was the comparison of primary outcome, no adjustment for multiple comparisons was considered in exploratory analyses such as secondary outcome comparisons, propensity score matched analysis, and factorial design analysis. All statistical analyses were conducted using SAS Studio (version 3.8; SAS Institute Inc., Cary, NC, USA). Statistical significance was accepted at a p-value of <0.05.

RESULTS

The baseline characteristics of patients receiving middle meningeal artery embolization and conventional retreatment are summarized in Table 1. The median age (p=0.003) of patients undergoing middle meningeal artery embolization was higher than that of patients receiving conventional retreatment. Symptomatic hematoma (p<0.001) was less frequent, the interval between initial treatment and retreatment (p<0.001) was shorter, and hematoma width (p=0.080) and midline shift were smaller (p=0.002) in patients receiving middle meningeal artery embolization. These differences appear to reflect the revised protocol in which the retreatment was initiated early before symptom development. These six variables with a baseline group difference with a p-value of <0.2 were included as covariates in outcome comparisons.

Of 96 patients receiving conventional retreatment, 92 (95.8%) underwent hematoma removal (burr-hole in 78 [81.3%] and craniotomy in 14 [14.5%]), and four (4.2%) refused retreatment and opted for continued follow-up due to poor neurological condition. Second recurrence occurred in 32 patients (33.3%). As a further retreatment for the second recurrence, burr-hole drainage (18 [18.7%]), craniectomy (two [2.1%]), middle meningeal artery embolization (four [4.2%]), or subduro-perintoneal

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shunt (two [2.1%]) was performed again. The families of six patients (6.3%) refused further treatment for second recurrence. Complications (Supplementary Table 1) occurred in 10 patients (10.4%) : acute subdural hematoma immediately following retreatment in four (4.2%), embolic infarction due to prolonged discontinuation of antiplatelet or anticoagulation therapy in four (4.2%), empyema in one (1.0%), and postoperative acute renal failure in one (1.0%). Six patients (6.3%) died from these

Table 1. Baseline characteristics of patients receiving middle meningeal artery and conventional retreatment

	MMA embolization (n=46; 32.4%)	Conventional retreatment (n=96; 67.6%)	*p*-value
Male	34 (73.9)	68 (70.8)	0.842
Age* (years)	80 (9.0)	74 (11.0)	0.003
Neurological status before chronic subdural hematoma development			1.000
mRS score, 0	42 (91.3)	88 (91.7)	
mRS score, ≥1	4 (8.7)	8 (8.3)	
Symptomatic hematoma†	8 (17.4)	58 (60.4)	<0.001
Interval between initial treatment and retreatment* (days)	35 (30.0)	54 (25.5)	<0.001
Medical history			
Trauma history	30 (65.2)	68 (70.8)	0.562
Chronic alcoholism	10 (21.7)	24 (25.0)	0.834
Hypertension	25 (54.3)	48 (50.0)	0.720
Diabetes mellitus	22 (47.8)	41 (42.7)	0.592
Cerebrovascular accident	4 (8.7)	12 (12.5)	0.583
Heart disease	8 (17.4)	18 (18.6)	1.000
Liver disease	2 (4.4)	8 (8.3)	0.499
Chronic renal failure	6 (13.0)	6 (6.3)	0.203
Use of antiplatelets or anticoagulants	22 (47.8)	37 (38.5)	0.363
Laboratory finding			
Platelet count* ($\times 10^3/\mu L$)	234 (95.0)	231 (98.0)	0.219
PT* (INR)	1.04 (0.150)	1.08 (0.110)	1.000
aPTT* (seconds)	30.5 (6.50)	30.7 (5.55)	0.402
Radiological finding			
Brain atrophy	24 (52.2)	40 (41.7)	0.281
Hematoma side			0.834
Bilateral	2 (4.4)	6 (6.2)	
Left	26 (56.5)	50 (52.1)	
Right	18 (39.1)	40 (41.7)	
Hematoma classification‡			0.852
Homogenous or laminar type	16 (34.8)	38 (39.6)	
Separated type	12 (26.1)	24 (25.0)	
Trabecular type	18 (39.1)	34 (35.4)	
Hematoma width* (mm)	21.6 (6.91)	23.0 (9.12)	0.080
Midline shift* (mm)	4.8 (1.92)	6.0 (4.26)	0.002

Values are presented as number (%) unless otherwise indicated. *Values are presented as median (interquartile range, [Q3–Q1]). †Symptomatic hematomas were defined as chronic subdural hematomas with severe headache or neurological deficits due to mass effect. ‡Hematoma was categorized with the Nakaguchi classification. MMA : middle meningeal artery, mRS : modified Rankin scale, PT : prothrombin time, INR : international normalized ratio, aPTT : activated partial thromboplastin time

complications. Neurological status returned to the level before chronic subdural hematoma development in 46 patients (47.9%).

Of 46 patients receiving middle meningeal artery embolization, no further management following the embolization was applied in 38 (82.6%) asymptomatic patients, while hematoma removal for symptom relief was added in eight (17.4%) symptomatic patients (burr-hole drainage in six [13.0%] and craniotomy in two [4.4%]). In all 46 cases, no dangerous anastomosis was observed and embolization was successful without procedural complications including cerebral infarction, central or branch retinal artery occlusion, hematoma formation in the femoral puncture site, and cranial nerve palsy. One patient (2.2%) experienced motor weakness 3 days after embolization, and thus underwent burr-hole drainage for symptom relief; this case was counted as second recurrence. Complications (Supplementary Table 1) occurred in one patient (2.2%), who contracted COVID-19 during admission and died from pneumonia. Neurological recovery was observed in 32 (69.6%).

The second recurrence rate was significantly lower in patients receiving middle meningeal artery embolization than in those receiving conventional retreatment (1/46 [2.2%] vs. 32/96 [33.3%]; crude OR, 0.065; 95% CI, 0.007–0.262; Table 2). This difference remained significant even when adjusted for age, symptomatic hematoma, interval between initial treatment and retreatment, hematoma width, and midline shift (adjusted OR, 0.056; 95% CI, 0.003–0.164; p=0.001). Complication rates did not differ significantly between patients receiving middle meningeal artery and conventional retreatment (1/46 [2.2%] vs. 10/96 [10.4%]; crude OR, 0.272; 95% CI, 0.029–1.214; adjusted OR, 0.203; 95% CI, 0.019–1.221; p=0.103), but neurological recovery was more frequent in patients receiving middle meningeal artery embolization and its rate difference was significant (32/46 [69.6%] vs. 46/96 [47.9%]; crude OR, 2.434; 95% CI, 1.183–5.192; adjusted OR, 3.147; 95% CI, 1.198–8.268; p=0.020).

The outcomes of the matched cohort were similar to those in the full cohort (Supplementary Table 2). Interaction between middle meningeal artery embolization and hematoma removal was not significant (p=0.163) and thus middle meningeal artery embolization (p=0.003) was shown to reduce the second recurrence rate independently of hematoma removal in the factorial design analysis (Supplementary Table 3).

DISCUSSION

The present study demonstrated that conventional retreatment for recurrent chronic subdural hematoma yielded a considerable rate of second recurrence, while middle meningeal artery embolization significantly reduced the second recurrence rate and improved neurological recovery. Complications in patients undergoing middle meningeal artery embolization were rare and less frequent than surgical complications which were observed after conventional retreatment.

In clinical practice, repeating surgical treatment still remains the main option for recurrent hematoma[3,4], although alternative treatment such as middle meningeal artery embolization has recently been introduced. The second recurrence rate following re-operation has been reported to range from 5.9% to 46.2%, which was not substantially different from the first recurrence rate observed after initial surgery[3,6-8,10,11,16,18,19]. However, re-operation has been associated with an increased risk of complications compared with initial surgery, and second recurrence is often accompanied by neurological deficits, resulting in poor clinical outcomes[3,6,7,16]. Consistent with previous studies, these findings were observed in patients who underwent conventional retreatment in the present study. These results suggest that conventional surgical retreatment may not be sufficient to optimize outcomes in recurrent chronic subdural hematoma.

Middle meningeal artery embolization can resolve the under-

Table 2. Primary and secondary outcomes

	MMA embolization	Conventional retreatment	Crude OR (95% CI)	Adjusted* OR (95% CI)	p-value
Second recurrence	1/46 (2.2)	32/96 (33.3)	0.065 (0.007–0.262)	0.056 (0.003–0.164)	0.001
Complications	1/46 (2.2)	10/96 (10.4)	0.272 (0.029–1.214)	0.203 (0.019–1.221)	0.103
Neurological recovery	32/46 (69.6)	46/96 (47.9)	2.434 (1.183–5.192)	3.147 (1.198–8.268)	0.020

Values are presented as number (%) unless otherwise indicated. *Each comparison of outcomes between patients receiving middle meningeal artery and conventional retreatment was adjusted for age, symptomatic hematoma, interval between initial treatment and retreatment, hematoma width, and midline shift. MMA : middle meningeal artery, OR : odds ratio, CI : confidence interval

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lying pathological conditions of chronic subdural hematoma, as demonstrated in recent prospective randomized trials[2,5,12,17]. Considering that recurrent chronic subdural hematoma represents a state of persistent bleeding from the outer membrane, middle meningeal artery embolization can be more effective in preventing second recurrence than conventional surgical retreatment, which is supported by results of the present study. Previous studies have shown that most patients with recurrent hematoma are elderly and have underlying comorbidities, which contribute to a higher rate of surgical complications[3,6,7,16]. To avoid surgery and its associated complication risk, we performed middle meningeal artery embolization early before symptom development, and thereby were able to reduce the overall complication rate. These findings indicate that middle meningeal artery embolization offers advantages of preventing second recurrence and reducing complications, which lead to improving neurological outcomes.

Although middle meningeal artery embolization resulted in neurological recovery in a greater proportion of patients compared with conventional retreatment, we found that a considerable number still had neurological sequelae which persisted despite successful retreatment even among those who underwent middle meningeal artery embolization. These outcomes were markedly inferior to those achieved after initial treatment. Therefore, prevention of first recurrence during initial treatment should be regarded as a critical therapeutic priority in management of chronic subdural hematoma.

This study has several limitations. First, its single-center retrospective design may have limited external validity and introduced selection bias. Second, the sample size was relatively small, which could affect the generalizability of the findings, although we collected more than 1000 patients who were treated in our institution over 30 years. In particular, because middle meningeal artery embolization has been recently introduced and to date, has not been widely performed, a nationwide survey or cohort study will be needed to enroll a sufficient number of patients receiving the embolization for recurrent chronic subdural hematoma. Finally, treatment decisions were based on institutional protocols rather than randomization, and unmeasured confounding factors could have influenced outcomes despite statistical adjustment.

CONCLUSION

We found that middle meningeal artery embolization for recurrent chronic subdural hematoma effectively prevented second recurrence and improved neurological recovery compared with conventional retreatment, with avoiding surgical complication. Our results suggest that middle meningeal artery embolization could be considered an effective and safe retreatment option for recurrent chronic subdural hematoma.

AUTHORS' DECLARATION

Conflicts of interest

No potential conflict of interest relevant to this article was reported.

Informed consent

This type of study does not require informed consent.

Author contributions

Conceptualization : GH; Data curation : BJK, GH; Formal analysis : BJK, GH; Methodology : GH; Project administration : BJK, HGK, JSK; Visualization : BJK, GH; Writing - original draft : BJK, GH; Writing - review & editing : HGK, JSK, JHP, SHO, MKK, BSC

Data sharing

None

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- **Supplementary materials**

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