INTRODUCTION

Chronic subdural hematoma (cSDH) is one of the most common neurological diseases and causes significant morbidity and mortality, especially among the elderly population.2–5 Surgical evacuation using bur holes or craniotomy remains the first-line treatment, especially for patients with significant brain compression, causing neurological symptoms. However, approximately 5–10% of patients require multiple procedures within 30–60 days.6–7 Patients without neurological symptoms and/or cerebral mass effect typically receive conservative treatment with close follow-up for progression of hemorrhage and/or symptoms. Even patients who receive conservative treatment have conditions that progress, requiring surgical intervention, with reports that as many as 84% of patients eventually need invasive treatment.8

Recently, middle meningeal artery (MMA) embolization has emerged as a potentially safe and effective method of treating cSDHs.5–11 Pertinent literature, however, remains limited, and consists of mostly small case series and individual case reports. In addition, none of the existing studies have compared different techniques for MMA embolization. This study reports a single-center experience with MMA embolization for cSDH and provides an analysis of surgical outcome by radiographic measure on follow-up imaging and clinical measures using the modified Rankin Scale (mRS) score and procedural complications. The primary aim of the report is to analyze various techniques used, including type of access approach (femoral vs radial), embolic material used, extent of penetration, and the MMA branches embolized.

METHODS

The endovascular treatment database at our institution (Barrow Neurological Institute, Phoenix, Arizona, USA) was retrospectively analyzed for all patients who underwent MMA embolization between January 1, 2018 and December 31, 2019. The study protocol was approved by St Joseph’s Hospital and Medical Center’s institutional review board in Phoenix, Arizona. The need for informed consent was waived owing to the low risk to study subjects. A total of 231 patients with a cSDH of at least 8 mm were managed at the institution during the study period. Forty patients underwent MMA embolization for cSDH. A variety of embolic agents were used for these procedures, including microspheres, n-butyl cyanoacrylate (nBCA), and ethylene vinyl alcohol copolymer (Onyx). The type of embolic agent used was based on attending preference, with a shift toward Onyx during the latter part of the study. When using Onyx, we typically attempt to achieve distal penetration and push Onyx through distal collaterals to other MMA vessels, allowing reflux back along the catheter to occlude the branch proximally. In each case, an attempt was made to achieve distal penetration and occlusion of the MMA branch proximally. In each case, an attempt was made to achieve distal penetration and occlusion of the MMA branch proximally.
allow reflux of the material proximally to occlude the MMA division, taking care to avoid penetration into collaterals to the orbit as well as the petrosal branch at the skull base. Patients with less than 30 days of follow-up were excluded, leaving 35 patients with a total of 41 cSDHs who were included in the study analysis. Information such as demographic characteristics, cSDH characteristics, cSDH treatment, procedural complications, and outcome were abstracted from the electronic medical record. Patients are followed up monthly with imaging until cSDH has resolved or the patient is stable without symptoms. A failed outcome was defined as either the need for surgical rescue at any time point and/or greater than 10 mm of hematoma residual or reaccumulation after MMA embolization on last follow-up imaging at least 30 days after embolization. Secondary outcomes included complete resolution of the cSDH and change in cSDH size on last follow-up imaging. cSDH sizes were measured on 2D axial CT, with complete resolution defined as no hematoma visualized on the last follow-up CT. Furthermore, change in cSDH size was measured as the hematoma difference from last-follow up CT (or when surgical rescue occurred) from the CT immediately prior to embolization. Depth of penetration was a subjective measurement but, in general, was defined as embolization close to the apex of the artery.

**Statistical analysis**

Statistical analysis was performed using SPSS Statistics Windows, version 26 (IBM Corp., Armonk, New York, USA). Patient demographic characteristics, SDH characteristics, and outcomes were reported using percentage and/or frequency. Comparisons of hematoma size and change in size were performed using independent sample t-test. χ² test was used to analyze treatment failure and complete resolution of the hematoma. A p value less than 0.05 was considered statistically significant.

**RESULTS**

Thirty-five patients were included in this analysis (mean±SD age, 68±12 years). Table 1 presents the demographic and clinical characteristics of these patients. The two most common presenting symptoms were focal neurological deficit (15 patients; 43%) and headache (14 patients; 40%). Surgery had previously failed for nine patients (26%), and conservative treatment had failed for six patients (17%). Transradial access was used in 21 patients (60%), with the balance of cases treated via a transfemoral approach. The mean preoperative mRS score was 2.0±1.4, and the mean follow-up mRS score was 1.7±1.2 with a mean follow-up of 120±75 days. Ten patients (29%) had a mRS score greater than 2, and one patient (3%) had a worse mRS score on follow-up. Only one patient (3%) experienced a procedural complication occurred, a cerebrovascular accident in a patient with a type III arch who underwent transfemoral embolization.

Table 1 includes the characteristics of the 41 cSDH procedures. Embolic agents included Onyx (n=29; 71%), particles (n=7; 17%), and nBCA (n=5; 12%). Both the anterior and posterior MMA divisions were occluded in 29 cSDHs (71%). Both proximal and distal penetration of these branches was achieved in 25 (61%) hematomas. Twenty-six cSDHs (63%) were completely resolved (figure 1), and surgical evacuation was required in only a single hematoma (2%).

No statistical differences in mean preoperative versus postoperative hematoma size, or change in size, was found when examining embolic materials (Onyx vs nBCA vs particles and/or coils), branches embolized (anterior and posterior vs anterior or posterior only), and depth of embolization (distal and proximal vs proximal only) (tables 2–4). In addition, no significant difference was found in the outcome measures (complete resolution vs failed treatment) between the various embolic agents or depths of penetration. However, a higher percentage of patients had complete resolution of cSDH when both MMA divisions

<table>
<thead>
<tr>
<th>Procedure characteristic</th>
<th>Patients (n=35)</th>
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<tbody>
<tr>
<td>Embolic agent</td>
<td></td>
</tr>
<tr>
<td>Onyx</td>
<td>29 (71)</td>
</tr>
<tr>
<td>Particles and/or coils</td>
<td>7 (17)</td>
</tr>
<tr>
<td>nBCA</td>
<td>5 (12)</td>
</tr>
<tr>
<td>MMA branches embolized</td>
<td></td>
</tr>
<tr>
<td>Posterior or anterior only</td>
<td>12 (29)</td>
</tr>
<tr>
<td>Both posterior and anterior</td>
<td>29 (71)</td>
</tr>
</tbody>
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patients (84%) to have hemorrhages that were stable or decreased in size with no significant procedural complications. Similarly, Ban et al analyzed 72 patients with cSDHs treated via MMA embolization and found only one patient with a treatment failure (defined as either rescue surgery and/or >10 mm of hemorrhage found on postoperative imaging), and no patients experienced complications. By comparison, in our study, only one patient (3%) experienced a treatment-related complication, and more than 97% of patients had successful MMA embolization with reduction of their hematoma without the need for additional interventions. Notably, the complication occurred early in our series in a patient with a type III arch for whom femoral access was used.

Given the significant vascular comorbidities often seen in this patient population, we subsequently began to assess aortic arch vessel imaging prior to these interventions and transitioned almost exclusively to a radial approach. Furthermore, of the cSDHs embolized, over 60% were completely resolved within 4–6 weeks on follow-up imaging.

Because MMA embolization for cSDHs remains a relatively novel procedure, direct comparison of techniques is lacking. Such evaluations are necessary to optimize this treatment. For instance, after entering the cranium through the foramen spinosum, the MMA courses through a groove in the greater wing of the sphenoid and divides into two branches, the anterior and posterior branches. In the present analysis, embolization of both branches experienced treatment failure. Once the MMA divides into the anterior and posterior branches, both branches continue distally to supply the dura (the anterior branch divides into small distal branches at the sphenoid wing of the sphenoid and divides into two branches, the anterior and posterior branches).
angle of the parietal bone that eventually reach the vertex and occipital region, whereas the posterior branch arcs on the squamous portion of the temporal bone, eventually branching into small distal arteries, at the parietal bone in front of the mastoid angle, which supply the posterior dura of the cranium. In the current analysis, although none of the patients for whom both distal and proximal MMA embolization was accomplished experienced treatment failure, this comparison was not statistically significant.

The majority of previous studies reported the use of micro-particles. Our analysis found no statistically significant difference between various embolic agents. Over time, we have transitioned to using Onyx for the majority of cSDH embolizations, and we have noted neither complications nor treatment failures using this material. Additionally, nearly 70% of the cSDHs embolized with Onyx completely resolved on short-term follow-up. Similarly, Waquas et al performed MMA embolization with Onyx in eight patients and reported no recurrences. Onyx may allow for deeper penetration, possibly preventing associated with lower complication rates. During the study, endovascular procedures; however, successful treatments have sedation may ultimately be preferred, or at a minimum, immediate postoperative extubation should be prioritized.

Traditionally, femoral artery access has been used for neuro-endovascular procedures; however, successful treatments have been performed recently with radial artery access, which are associated with lower complication rates. During the study, our institution moved into a radial first practice due to these lower rates of access site complications. Of the 21 patients with radial access, none experienced a complication or treatment failure. Hence, a transradial approach for MMA embolization of cSDH provides similar treatment success to that of transfemoral access but without the potentially life-threatening access site complications.

Owing to its retrospective nature, this study is subject to all of the biases inherent in retrospective analyses, as well as those inherent in studies with small sample sizes. In addition, treatment approaches and outcome measures were determined on the basis of the on-call attending physicians’ preferences without a set institutional algorithm or protocols for follow-up imaging. However, in general, treatment approaches are primarily based on three categories: observation with or without medical treatment such as corticosteroids or statins in patients with small asymptomatic cSDHs <8 mm in diameter, MMA embolization or observation in patients without focal neurologic deficit with cSDHs ≥8 mm in diameter and with or without midline shift, surgery with or without MMA embolization in patients with symptomatic or large cSDH with >5 mm midline shift. Outcome measures are based on radiographic measure on monthly follow-up imaging and clinical measure using the mRS score. These factors impose further possible selection bias to this study.

CONCLUSION

Our institution’s experience with MMA embolization for cSDH has demonstrated promising outcomes and is associated with a low rate of treatment failure. In addition, as MMA embolization for cSDH has evolved, our center now favors transradial access for Onyx embolization, which is both safe and efficacious. Furthermore, embolization of both the anterior and posterior MMA branches may be associated with increased odds of complete resolution.

Acknowledgements The authors thank the Neuroscience Publications staff at Barrow Neurological Institute for assistance with manuscript preparation.

Contributors All authors made substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work; and drafted the work or revised it critically for important intellectual content; and provided final approval of the version to be published; and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests AFD is a consultant for Medtronic, Penumbra, Cerenovus, Stryker, and Kowser.

Patient consent for publication Not required.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement There are no additional data to share.

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REFERENCES


