Endoscope-assisted techniques for evacuation of acute subdural haematoma in the elderly: the lesser of two evils? A scoping review of the literature

Authors

Spencer R[1], Manivannan S[2], Zaben M[3]

Affiliations

1. Department of Neurosurgery, Institute of Neurological Sciences, Queen Elizabeth University Hospital, Glasgow, UK
2. Department of Neurosurgery, Southampton General Hospital, Southampton, UK
3. Department of Neurosurgery, University Hospital of Wales, Cardiff, UK

Corresponding Author

Dr. Malik Zaben

Neuroscience and Mental Health Research Institute (NMHRI),

School of Medicine,

Cardiff University

Room 4FT 80E, 4th Floor, University Hospital Wales,

Heath Park

Cardiff

CF14 4XN

Tel: 02920743861

Email: ZabenM@cardiff.ac.uk

ORCID: 0000-0002-7446-4532

Highlights

- Acute subdural haematoma in the elderly is associated with devastating outcomes
- Endoscope-assisted evacuation may be a viable alternative to large craniotomy
- Potential for procedure to be performed under local anaesthesia
- Reported outcomes are variable, likely related to heterogeneous patient selection
- Further studies are required to ascertain the optimal patient cohort

Abstract

Introduction: Surgical evacuation of acute subdural haematoma (ASDH) in the elderly remains a point of contention due to the significant associated mortality. Therefore, there is a dire need for alternative treatment options. Endoscope-assisted techniques (EAT) have been increasingly reported over the last decade with variable outcomes. In this scoping review, we identify studies reporting the use of EAT for ASDH evacuation in elderly patients. Outcomes and patient selection criteria are discussed to identify patients that may benefit from EAT.

Methods: A multi-database literature search was performed between January 1990 and January 2021. Studies including patients aged 60 years or above who underwent EAT for ASDH evacuation with reported outcomes were included.

Results: A total of 13 studies and 122 patients were eligible for inclusion. Patient age ranged from 65 to 101 years, and average age from 78.6 to 87.4 years. High comorbidity burden, advanced age, absence of adverse imaging features, and pre-operative neurological status were the most common eligibility criteria for EAT. 52% of all procedures were performed under local anaesthetic (LA). Mortality rates ranged between 0 and 40%, whilst favourable outcomes ranged between 26.7 and 96.4%. Re-bleed was the most commonly reported complication, ranging between 0 and 13%.

Conclusions: EAT pose a viable compromise for elderly patients with ASDH that may be unfit for GA. Heterogeneity of patient selection criteria prevents meaningful comparison between EAT and other approaches, and there is a clear impact of patient selection on outcome among studies reporting EAT. Further studies are required to identify the patient cohort that may benefit from this approach.

Key Words- geriatric, acute subdural haematoma, endoscopic neurosurgery, minimally invasive, traumatic brain injury

Declarations

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflicts of interest/Competing interests

All authors report no conflicting or competing interests in relation to this work.

Availability of Data and Material

Data available on request to corresponding author.

Code availability

Not applicable for the present manuscript.

Ethics approval

This study follows the principles of the declaration of Helsinki. As a literature-based study no formal ethical approval was required.

Consent to participate

Not applicable for the present study

Consent for publication

All authors have reviewed the manuscript and are in agreement with submission for publication in its current form.

Authors' contributions

Dr Robert Spencer: Methodology, Validation, Investigation, Writing – Original Draft, Review and Editing, Visualisation;

Dr Susruta Manivannan: Conceptualisation, Methodology, Validation, Writing – Review and Editing, Visualisation, Supervision;

Dr Malik Zaben: Conceptualisation, Writing – Review and Editing, Supervision

1. Introduction

Traumatic brain injury (TBI) is a global public health problem, causing significant mortality and morbidity worldwide. However, with a growing elderly population, the TBI patient demographic has shifted towards elderly patients suffering from falls-related head injuries. The dire implications of this are illustrated by the disproportionately high mortality seen in these patients across the world[1-3]. Acute subdural haematoma (ASDH) is a particularly ominous traumatic pathology in this age group, with a 6-month mortality rate as high as 58%[4]. It is characterised by the accumulation of acute blood beneath the dura mater, causing mass effect on the brain, often featuring other signs of injury from the initial impact[5].

Management of patients with ASDH consists of surgical intervention or conservative treatment. Traditionally, surgical intervention for ASDH comprises a trauma craniotomy for haematoma evacuation, although decompressive craniectomy (DC) may be required in instances of significant cerebral swelling. Indications for surgical intervention revolve around the Brain Trauma Foundation Guidelines from almost two decades ago, and include the following: ASDH thickness >10mm or midline shift (MLS) >5mm on computed tomography (CT) imaging, deteriorating consciousness, or elevated intracranial pressure on monitoring. However, the relevance of these guidelines to the elderly population has been increasingly questioned due to the high risk of poor outcomes following surgery[5]. Indeed, trauma craniotomies are unfavourable in the elderly due to: (i) risks of the procedure such as seizures, infection, stroke, and bleeding; (ii) risks of general anaesthetic (GA) such as pneumonia; and (iii) difficulty managing associated co-morbidities and anticoagulant use.

Therefore, there has been increasing interest in alternative management strategies for this cohort.

In recent years, several studies have reported the use of novel endoscope-assisted techniques (EAT) as opposed to open craniotomy for the surgical management of ASDH. This raises the exciting prospect of offering surgical intervention for elderly patients who may not tolerate conventional techniques. Indeed, avoiding the use of GA and achieving ASDH evacuation with a smaller craniotomy may, theoretically, result in less surgical morbidity. However, the outcomes and indications for EAT remain unclear. Therefore, we performed a scoping review of the literature to examine the current evidence for EAT in the management of ASDH in the elderly. Moreover, we propose a possible algorithm that might be employed in decision making between conventional craniotomy and EAT for this group of patients.

2. Methods

2.1 Literature Search

A multi-database (MEDLINE, EMBASE, Web of Science) search was performed between January 1990 and January 2021 in order to capture all possible relevant articles (**Figure 1**). The following search terms were used: "subdural"; "neuro(-)endoscop*"; "endoscop*" and "minimally invasive". Eligible articles were restricted to English language, and the bibliographies of included studies were screened for further relevant studies.

2.2 Study Selection

Studies meeting the following selection criteria were included: (i) patient age of 60 years or above; (ii) endoscope-assisted surgical technique for ASDH evacuation; (iii) clinical outcome reported. Exclusion criteria included: (i) diagnosis of acute-on-chronic, subacute or chronic SDH; (ii) abstracts, conference presentations, editorials and expert opinions. Studies including patients younger than 60 years or with subacute, acute-on-chronic or chronic haematoma were only included if the management and clinical outcomes were specifically reported for the target population. Although dubiety exists around the distinction between acute and subacute SDH, for the purposes of this review, the diagnosis reported in the original articles was used for the selection process and the definitions used in individual articles is reported in our results.

2.3 Data Extraction

The following variables of interest were extracted from included studies by author RS: number of patients, age, gender, baseline functional status, comorbidities, use of antithrombotic agents, mechanism of injury, pre-operative GCS and pupillary light reaction, imaging findings, indications for EAT as compared to conventional craniotomy/decompressive craniectomy or conservative management, surgical technique, choice of anaesthetic, operative duration, intra-operative identification of active bleeding points, mortality and/or functional outcome, and duration of follow up. Narrative data synthesis was performed. Glasgow Outcome Score and modified Rankin Scale were each dichotomised into good (GOS 4-5, mRS 0-3) and poor (GOS 1-3, mRS 4-6) outcome categories. Studies reporting separate cohorts of patients undergoing EAT or conventional craniotomy were examined for any comparison between treatment groups.

3. Results

A total of 1539 articles were screened, resulting in 13 articles eligible for final inclusion (see **Table 1**)[6-18]. This included single centre retrospective studies (n=8; 5-28 patients), case reports (n= 4), and a case series of two patients. Baseline demographics and patient selection criteria for the use of EAT were reported in all studies (**Table 2**).

3.1 Demographics

The age range of included patients was 65 to 101 years, with an average reported age (in studies with >2 patients) of between 78.6[15] and 87.4[14]. The percentage of male patients (in studies with n>2) ranged between 40%[16] and 80%[14]. Advanced age was stated as a factor favouring the use of EAT in six studies[6, 7, 9, 11, 13, 17]. Comorbidity was reported as a factor favouring EAT in eight studies[7, 9, 11, 12, 14-17]. However, no objective indices of comorbidity burden, severity or frailty were used in patient selection. One study reported that terminal cancer was an exclusion criterion from any form of operative management[18], but no other study reported the influence of any specific comorbidity on eligibility. The use of antithrombotic medications or other coagulopathy was reported as a factor influencing the choice to use EAT in eight studies[8, 9, 11-13, 15, 16, 18]. Five studies reported this as an exclusion criterion for EAT[8, 11, 13, 15, 18], whereas three studies reported coagulopathy as a favourable factor[9, 12, 16]. In studies that considered coagulopathy a contraindication for EAT, it was unclear whether conventional craniotomy shared the same contraindication.

3.2 Definition of ASDH

The definition of 'acute' SDH varied slightly between authors with many using both clinical and radiological features. Twelve studies defined ASDH as a subdural haematoma presenting with a history of recent trauma[6-10, 12-18], eleven defined it by hyperdense SDH on CT imaging[6-12, 14-17], and one paper commented that all included patients had a "solid" SDH[11].

3.3 Injury-associated factors

Mechanism of injury was reported in 11 studies[6-9, 12-18]. Falls accounted for the majority of patients in all studies, ranging from 67%[15] to 100%[6, 7, 9, 12-14, 16, 17] when the mechanism of injury was known. Severity of TBI was reported in all studies, and pre-operative GCS was reported by 12 studies[6-14, 16-18] (range 3-15). Pre-operative pupillary reactivity was reported in eight studies[6, 7, 9-12, 15, 16], with between 0[10] and 26.7%[16] of patients presenting with an absent pupillary light reflex (PLR). Pre-operative neurological status, including GCS and PLR, formed a component of eligibility criteria in three studies[9, 10, 18]. A further two studies reported the patient being 'symptomatic' of their ASDH as an indication for surgery[8, 14], including those with deteriorating consciousness levels. Di Rienzo et al only included patients with GCS 9-11 who were maintaining their own airway. In the two-patient case series, deteriorating GCS was reported as an indication for EAT[9]. Finally, one study excluded all patients with pre-operative GCS 3[18].

3.4 Radiological parameters

Imaging parameters were reported in six studies[6, 7, 9, 12, 16, 18]. ASDH thickness was reported in five studies[6, 7, 9, 12, 18], while ASDH volume was estimated by volumetric analysis in one study[16]. Midline shift (MLS) was reported in six studies[6, 7, 9, 12, 16, 18], although it was not quantified in two[7, 12]. The presence of additional intracranial injuries was reported in two studies accounting for a total of three patients[9, 12]. One included a patient with traumatic subarachnoid haemorrhage, and a small extradural haematoma underlying an occipital fracture[12]. The other included two patients with bifrontal contusions and frontotemporal contusions ipsilateral to the ASDH, respectively[9]. Imaging parameters were reported as important factors in patient selection for EAT in eight studies[8, 11, 13-18]. This included features of the ASDH, such as evidence of enlarging haematoma as a contraindication[16] or 'moderately thick or larger' haematoma as an indication for surgery[13]. However, neither provided quantitative descriptors for these indications. Three studies excluded patients with cerebral contusions or intra-parenchymal haemorrhage[8, 13, 17]. Eight studies specified that only patients with imaging features consistent with a low likelihood of requiring DC were eligible for EAT[11-18]. This included features such as the absence of cerebral oedema, or the impression that the majority of mass effect was secondary to ASDH rather than cerebral oedema.

3.5 Operative Technique

All included studies reported a minimal craniotomy and use of an endoscope to extend the visible operative field. Operative techniques are summarised in **Table 3**. The general approach was in keeping with a conventional craniotomy: a perforator drill was used to create a single burrhole, and a craniotome used to create a small craniotomy. The visible haematoma underlying the craniotomy was suctioned or gently removed with forceps under direct vision. Then, an endoscope was introduced to guide further evacuation and identify active bleeding points for electrocauterisation. **Figure 2** comprises schematics presented by two included studies, demonstrating the EAT employed in their centres[8, 13], while **figures 3** and **4** include intra-operative photographs.

Craniotomy size was reported by 12 studies[6-8, 10-18], ranging between 2[8, 16] and 5cm[10] in diameter. One case report utilised two separate 2.5cm-diameter craniotomies, situated anteriorly and posteriorly[6]. The location of the craniotomy was reported by all but two studies. The craniotomy was positioned over the thickest part of the haematoma in seven studies[8, 10, 11, 13, 14, 16, 18], a frontal location in two studies[7, 9], and at the angle between the superior temporal line and the coronal suture in one study[15]. The latter position was advocated as offering the optimal visual field and accessibility to distant parts of the haematoma[15]. The identification of bleeding points was reported in nine studies[6-8, 11, 13-17]. A rigid endoscope was used in 10 studies[6-9, 13-18], a flexible endoscope in two studies[11, 12] and the type of endoscope was unspecified in one study[10]. Diameter of endoscope varied between 2.7mm[9] and 5mm[11], and studies variably used both 0º and 30º endoscope viewing angles. The rationale for choice of endoscope was not reported in any of the included studies.

Anaesthetic techniques were reported in all studies. Four studies used local anaesthetic (LA) [7-9, 16], three studies used GA[6, 12, 18], and two studies used sedation[10, 13, 17] alone. The remaining three studies included patients that underwent ASDH evacuation under LA or GA[11, 14, 15]. In one study, three patients required intra-operative conversion from LA to GA due to patient intolerance or cardiovascular instability[11]; while in another study, all 28 procedures began under LA but sedation was required in 5 due to excessive patient movement[10]. Operative duration was reported in 10 studies[6-8, 10-13, 15, 16, 18], with median duration (in studies with >2 patients) varying between 65 minutes[10] and 111 minutes[18]. Patient experience of EAT performed under LA was reported by one study, stating that 2 of their 28 patients remembered a vibration sensation but the others could not remember anything[10].

3.6 Outcomes

All studies reported clinical outcomes (**Table 1**). Both mortality and functional outcome were reported by 11 studies[6-8, 10-17], whilst two studies reported mortality[9] or functional outcome[18] alone. Outcome was reported at discharge in 11 studies, three months post-injury in one study[10] and six months post-injury in another[16]. Mortality rate (in studies with >2 patients) ranged from 0[8, 11] to 40%[14]. The percentage of patients with a 'good' outcome (in studies with >2 patients) ranged between 26.7%[14] and 96.4%[10]. Across the five studies with sample sizes of less than 3 patients, (n=6)[6, 7, 9, 12, 17] there were no reported deaths and 'good' outcomes were reported in all four patients that were assessed. None of the studies evaluated predictors of outcome within their cohort.

3.7 Complications

Surgical complications were mentioned in the methodology of all studies but were only encountered in five studies[10, 11, 14, 16, 18] (**Table 3**). The most common complication was rebleeding. The reported incidence of rebleeding following EAT for evacuation of ASDH varied between 0%[13, 15] and 13%[16]. Across studies that reported rebleeding as a potential complication, representing 115 patients, rebleeding occurred in four[6-13, 15-18]. No studies analysed for predictors of rebleeding. Post-operative development of chronic

SDH was reported in one patient[11] . Post-operative seizures were reported in nine out of 28 patients in one study[10]. One study used prophylactic anti-epileptic medications, but did not specifically report seizures as a complication[6]. The remaining studies did not report seizures as a complication. Medical complications were reported in three studies[10, 11, 14]. This included pneumonia in one patient in each of the three studies, while one patient developed acute kidney injury on a background of chronic kidney disease in one study[14] and one patient developed congestive cardiac failure in another[11].

3.8 Example cases

Figures 3 and **4** are adapted from Ichimura et al[14] and Kawasaki et al[11], respectively. **Figure 3** illustrates the case of a 93-year-old woman who presented with depressed consciousness (GCS E3V4M6) and right hemiparesis after a fall. Following the operation to evacuate the haematoma, she had recovered to GCS 14 with resolution of the limb weakness. She was discharged at her baseline functional status (mRS 3)[14]. **Figure 4** is a case of an 83-year-old man who took warfarin due to atrial fibrillation. He presented after a fall at home with depressed consciousness (GCS E1V2M2) and intact PLR. His operation started under LA with sedation, however this was converted to GA prior to clot evacuation due to haemodynamic instability. He was discharged to a rehabilitation centre after recovery to GCS 12 (E4V3M5), mRS 4 (baseline not reported)[11].

4. Discussion

Outcomes following conventional surgical evacuation of ASDH in the elderly are poor, with some studies reporting in-patient mortality of over 50%[19-21], and poor functional outcome in 80% or above[20-25]. With a growing elderly population, there is a dire need for alternative treatment options to conventional surgical evacuation and conservative management. Whilst EAT may offer an effective surgical compromise for elderly patients, the heterogeneity of eligibility criteria in the current literature means further studies are required to accurately identify which patients may benefit. We identified 13 studies detailing the use of EAT for ASDH evacuation in 122 patients aged 60 years or above. Of these patients, 11 died, while a further 28 patients had poor outcomes (GOS 1-3) at hospital discharge (n=22) or 6 months (n=6). However, the proportion of deaths and poor outcomes varied significantly between studies. Mortality rates ranged between 0 and 40%, whilst favourable outcomes were seen in up to 97% of patients in one study[10]. Therefore, whilst a cursory evaluation of outcome data may suggest superiority of EAT over craniotomy or DC, the effects of patient selection criteria must be assessed. Only one study directly compared EAT (n=15) with craniotomy (n=20) for evacuation of ASDH in the elderly[16]. There were no statistically significant differences between the groups with respect to: age, comorbidity, admission GCS and pupillary response, ASDH volume and degree of MLS, use of antithrombotics, and laboratory coagulation parameters. Both intra-operative blood loss (median 20ml vs 200ml, p=0.002, Mann-Whitney *U* test (MWUT)); and the total time in the operating room (median 120 minutes vs 180 minutes, p=0.005) were significantly lower in the EAT group. However, no significant differences were identified with respect to in-hospital mortality (20% vs 10%; EAT vs craniotomy;, p=0.63, Chi-square test), or modified Rankin Scale at six months (median 5 vs 5; p=0.91, MWUT).

Although we reviewed the literature for use of EAT in patients aged over 60, the minimum age of patients across included studies was 65 years. Advanced age was listed as an eligibility criterion for EAT, but it was unclear how this cut-off was defined[6, 7, 9, 11, 13, 17]. Indeed, in recent decades our interpretation of "advanced age" has shifted considerably, with surgical treatments being offered to patients that would not have been considered previously[26]. Given that the mean age of included patients ranged from 78.6[15] to 87.4 years[14], it may suffice to define patients aged 80 years or above as eligible for EAT. Similarly, whilst advanced co-morbidities were mentioned as an eligibility criterion for EAT in eight studies[8, 9, 11-13, 15, 16, 18], none of these studies defined these co-morbidities. The use of metrics such as the Charlston Comorbidity Index (CCI) may provide an objective approach to patient selection. The importance of pre-admission residence, or metrics such as Karnofsky Performance Status (KPS)[27] or Clinical Frailty Score (CFS)[28] must be explored in future studies. For example, one recent study demonstrated that the modified Frailty Index was predictive of 30-day mortality and poor functional outcome in elderly patients with ASDH[29]. It is likely that EAT would be suitable for patients whose baseline function is too poor for craniotomy or DC, but not to the extent of being unable to tolerate any surgical intervention.

Coagulation status was discussed in the majority of included studies, but its impact on eligibility for EAT was conflicting. Five studies reported coagulopathy as an exclusion criterion[8, 11, 13, 15, 18], while three studies reported it as a factor favouring EAT[9, 12, 16]. The former was justified by concerns that intra-operative bleeding would be more difficult to control with the use of an endoscope[8, 11, 13, 15, 18], whilst the latter highlighted the desirability of a smaller scalp wound and craniotomy in patients with a higher risk of bleeding[9, 12, 16]. Whilst there is no conclusive evidence regarding coagulopathy in EAT, multiple studies demonstrated effective control of bleeding points with an endoscopic technique[7, 11, 13-16], and, as mentioned earlier, one study demonstrated significantly lower intra-operative blood loss compared to craniotomy[16]. Therefore, EAT could still offer a viable alternative in patients with abnormal coagulation status.

Pre-operative neurological status was reported in the majority of studies and was used for patient selection in some. The largest included study (n=28) only included patients with pre-operative GCS 9-11 who were maintaining their own airway. This was to ensure that the use of GA could be avoided[10]. Although excellent outcomes were reported, it is difficult to assess whether this was due to their strict inclusion criteria. Indeed, several studies of conventional surgical approaches in elderly patients with ASDH have reported pre-operative neurological status as a significant predictor of outcome[19, 20, 25, 30-34]. For example, another study included patients with a pre-operative GCS ranging 3-15[11]. Of the 18 eligible patients, almost half had poor outcome at discharge. Hence, pre-operative neurological status must be taken into account when evaluating outcomes with EAT.

Radiological parameters formed a component of eligibility criteria in several studies. Broadly, this included: (i)features of the ASDH such as thickness, volume, or changing size[13, 16]; (ii)presence of other traumatic intracranial lesions[8, 13, 17]; and (iii)indicators that DC may be required, such as significant cerebral oedema[11-18]. The underlying rationale was that EAT may be insufficient to relieve mass effect from any factors outside of the ASDH alone. This highlights the importance of not comparing EAT with craniotomy or DC at present, as patient selection is significantly different. For example, one study demonstrated that the requirement for DC due to significant cerebral oedema was predictive of poor outcome in elderly patients with ASDH[30]. Therefore, whilst EAT may be considered in cases of isolated ASDH, other traumatic intracranial findings may be a relative contra-indication.

The option of performing EAT under LA is one of its major advantages, as this provides a surgical alternative for patients that may not tolerate GA. The majority of included studies reported successful use of LA, with or without sedation. Two studies reported the use of dexmedetomidine, an α2-adrenoceptor agonist with sedative, anxiolytic, analgesic and cardiovascular stabilising effects[35], with no requirement for conversion to GA or airway securement[13, 17]. However, one study reported conversion from LA to GA in three patients[11]. Among these patients there were no deaths, but only one had a favourable outcome at discharge. Suitability for LA implies the patient is able to maintain their own airway. This narrows the suitable patient cohort for EAT considerably, and is likely in-keeping with the selection criteria employed by Di Rienzo et al[10]. Another consideration is the risk of excessive patient movement intra-operatively following ASDH evacuation, which may necessitate sedation or conversion to GA. Essentially, further studies are required to clarify patient suitability for the choice of anaesthetic and a sufficiently experienced neuro-anaesthetist must be immediately available to consider sedation or conversion to GA.

All studies reported similar surgical approaches, involving a minimal craniotomy and use of an endoscope to guide haematoma evacuation and control of bleeding points. Differences in technique were identified with respect to: (i)craniotomy position; (ii)craniotomy size; and (iii)choice of endoscope (**Table 1**). The majority of studies advocated a craniotomy position overlying the region of maximal ASDH thickness[8, 10, 11, 13, 14, 16, 18] in order to perform limited initial evacuation under direct vision. However, a recent cadaveric study demonstrated that this may not be the optimal point for rigid endoscopic access[36]. They demonstrated that craniotomy located between the mid-pupillary line and superior temporal line at the convexity of the parietal bone provided optimal access to the entire subdural space. This was found to be superior to other sites including one centimetre anterior or posterior to the coronal suture in the mid-pupillary line. Further cadaveric studies with the use of a flexible endoscope may reveal greater flexibility in choice of optimal craniotomy placement. Given the cerebral atrophy seen in older patients, several authors have reported greater ease of using an endoscope to perform a comprehensive inspection of the subdural space[9, 13, 15]. The majority of studies used rigid endoscopes, whilst two studies used flexible endoscopes. Unfortunately, none of the studies discussed their rationale for the choice of rigid vs flexible endoscope, nor the viewing angle employed. This, along with the previously noted heterogeneity in patient selection renders attempts to link endoscope choice with outcomes impossible and further work is required to evaluate this. It may be that a flexible endoscope is a better choice for this particular indication in order to allow complete inspection of the subdural space around the curvature of the brain without compressing the cortical surface with the scope. However, given that suction and irrigation instruments remain separate to the endoscope apparatus and inflexible themselves in studies to date, this improved visualisation might be irrelevant to the degree of evacuation achieved.

Rebleeding rates were low across included studies, with a crude pooled incidence of 3.5%. Although this estimate is clearly not a robust one, a recent large study of an elderly ASDH cohort undergoing standard craniotomy or DC encountered rebleeding in 9.5% of all surgically-managed patients[25]. Therefore, it is possible that EAT is associated with a lower rebleeding rate, however this obviously requires further evaluation.

4.2 Limitations

This scoping review is limited primarily by the relatively small number of elderly patients reported in the literature undergoing EAT for the treatment of ASDH. Compounding this, there is significant heterogeneity between studies, both in terms of patient selection and operative and anaesthetic techniques used, thus precluding meaningful meta-analysis of outcome data.

4.3 Summary of the evidence

The question of whether EAT is superior to conventional trauma approaches remains unanswered at this stage. However, this is due to the fact that patient selection will almost always differ between these two groups. **Figure 5** provides a summary of the factors that require consideration when offering treatment to the elderly patient with ASDH, with features that might favour conservative management, EAT and conventional craniotomy, respectively. Based on the available evidence, EAT is applicable to patients with specified pre-operative neurological status, imaging findings, suitability for anaesthetic, and co-morbidity burden. However, larger scale studies with patients matched for baseline variables must be performed to compare surgical approaches. It would also be useful to clarify the subset of patients that may not benefit from conventional approaches, but could be offered EAT rather than conservative management.

5. Conclusion

Surgical management of ASDH in the elderly remains a point of contention, and there is a dire need for alternative treatment options. Over the last decade there have been increasing reports of using EAT for ASDH evacuation in the elderly. Given the poor outcomes associated with conventional craniotomy or DC, EAT represents a promising alternative. However, current evidence is limited to a specific cohort of patients, and further studies are required to clarify which patients would be most likely to benefit from this approach. Comparisons between conventional surgical approaches and EAT for ASDH evacuation cannot be made at this stage due to differences in surgical candidate selection. Larger scale multi-centre studies are required to validate outcomes with EAT and identify the optimal patient cohort.

6. References

[1] A.B. Peterson, S.R. Kegler, Deaths from Fall-Related Traumatic Brain Injury - United States, 2008-2017, MMWR Morb Mortal Wkly Rep 69(9) (2020) 225-230.
[2] W. Peeters, R. van den Brande, S. Polinder, A. Brazinova, E.W. Steyerberg, H.F. Lingsma, A.I. Maas, Epidemiology of traumatic brain injury in Europe, Acta Neurochir (Wien) 157(10) (2015) 1683-96.
[3] M.A. Kirkman, T. Jenks, O. Bouamra, A. Edwards, D. Yates, M.H. Wilson, Increased mortality associated with cerebral contusions following trauma in the elderly: bad patients or bad management?, J Neurotrauma 30(16) (2013) 1385-90.
[4] K.J. Whitehouse, D.S. Jeyaretna, D.G. Enki, P.C. Whitfield, Head Injury in the Elderly: What Are the Outcomes of Neurosurgical Care?, World Neurosurg 94 (2016) 493-500.
[5] M.R. Bullock, R. Chesnut, J. Ghajar, D. Gordon, R. Hartl, D.W. Newell, F. Servadei, B.C. Walters, J.E. Wilberger, G. Surgical Management of Traumatic Brain Injury Author, Surgical management of acute subdural hematomas, Neurosurgery 58(3 Suppl) (2006) S16-24; discussion Si-iv.
[6] P.J. Codd, A.S. Venteicher, P.K. Agarwalla, K.T. Kahle, D.H. Jho, Endoscopic burr hole evacuation of an acute subdural hematoma, J Clin Neurosci 20(12) (2013) 1751-3.
[7] H. Kon, A. Saito, H. Uchida, M. Inoue, T. Sasaki, M. Nishijima, Endoscopic surgery for traumatic acute subdural hematoma, Case Rep Neurol 5(3) (2013) 208-13.

[8] K. Yokosuka, M. Uno, K. Matsumura, H. Takai, H. Hagino, N. Matsushita, H. Toi, S. Matsubara, Endoscopic hematoma evacuation for acute and subacute subdural hematoma in elderly patients, J Neurosurg 123(4) (2015) 1065-9.
[9] R. Tamura, Y. Kuroshima, Y. Nakamura, Neuroendoscopic Removal of Acute Subdural Hematoma with Contusion: Advantages for Elderly Patients, Case Rep Neurol Med 2016 (2016) 2056190.
[10] A. Di Rienzo, M. Iacoangeli, L. Alvaro, R. Colasanti, L. Somma, N. Nocchi, M. Gladi, M. Scerrati, Mini-Craniotomy under Local Anesthesia to Treat Acute Subdural Hematoma in Deteriorating Elderly Patients, J Neurol Surg A Cent Eur Neurosurg 78(6) (2017) 535-540.
[11] T. Kawasaki, Y. Kurosaki, H. Fukuda, M. Kinosada, R. Ishibashi, A. Handa, M. Chin, S. Yamagata, Flexible endoscopically assisted evacuation of acute and subacute subdural hematoma through a small craniotomy: preliminary results, Acta Neurochir (Wien) 160(2) (2018) 241-248.
[12] T.S. Maruya J, Hasegawa R, Saito A, Nishimaki K, Fujii Y, Endoscopic hematoma evacuation following emergent burr hole surgery for acute subdural hematoma in critical conditions: Technical note, Interdisciplinary Neurosurgery 12 (2018) 48-51.
[13] H. Matsumoto, H. Minami, H. Hanayama, Y. Yoshida, Endoscopic Hematoma Evacuation for Acute Subdural Hematoma in the Elderly: A Preliminary Study, Surg Innov 25(5) (2018) 455-464.
[14] S. Ichimura, K. Takahara, M. Nakaya, K. Yoshida, Y. Mochizuki, M. Fukuchi, K. Fujii, Neuroendoscopic hematoma removal with a small craniotomy for acute subdural hematoma, J Clin Neurosci 61 (2019) 311-314.
[15] S.C. Hwang, D.S. Shin, Endoscopic Treatment of Acute Subdural Hematoma with a Normal Small Craniotomy, J Neurol Surg A Cent Eur Neurosurg 81(1) (2020) 10-16.
[16] M. Katsuki, Y. Kakizawa, A. Nishikawa, K. Kunitoki, Y. Yamamoto, N. Wada, T. Uchiyama, Fifteen Cases of Endoscopic Treatment of Acute Subdural Hematoma with Small Craniotomy under Local Anesthesia: Endoscopic Hematoma Removal Reduces the Intraoperative Bleeding Amount and the Operative Time Compared with Craniotomy in Patients Aged 70 or Older, Neurol Med Chir (Tokyo) 60(9) (2020) 439-449.
[17] K.R. Kuge A, Mitobe Y, Yamaki T, Sato S, Saito S, Sonoda Y, Delayed acute subdural hematoma treated with endoscopic procedure: A case report, Surgical Neurology International 11 (2020).
[18] K. Miki, M. Nonaka, H. Kobayashi, Y. Horio, H. Abe, T. Morishita, M. Iwaasa, T. Inoue, Optimal surgical indications of endoscopic surgery for traumatic acute subdural hematoma in elderly patients based on a single-institution experience, Neurosurg Rev (2020).
[19] A.K. Petridis, L. Dorner, A. Doukas, S. Eifrig, H. Barth, M. Mehdorn, Acute subdural hematoma in the elderly; clinical and CT factors influencing the surgical treatment decision, Cent Eur Neurosurg 70(2) (2009) 73-8.
[20] N. Benedetto, C. Gambacciani, N. Montemurro, R. Morganti, P. Perrini, Surgical management of acute subdural haematomas in elderly: report of a single center experience, Br J Neurosurg 31(2) (2017) 244-248.
[21] S. Bus, D. Verbaan, B.J. Kerklaan, M.E.S. Sprengers, W.P. Vandertop, J. Stam, G.J. Bouma, P. van den Munckhof, Do older patients with acute or subacute subdural hematoma benefit from surgery?, Br J Neurosurg 33(1) (2019) 51-57.
[22] M. Hamed, P. Schuss, F.H. Daher, V. Borger, A. Guresir, H. Vatter, E. Guresir, Acute Traumatic Subdural Hematoma: Surgical Management in the Presence of Cerebral

Herniation-A Single-Center Series and Multivariate Analysis, World Neurosurg 94 (2016) 501-506.
[23] A. Merzo, S. Lenell, L. Nyholm, P. Enblad, A. Lewen, Promising clinical outcome of elderly with TBI after modern neurointensive care, Acta Neurochir (Wien) 158(1) (2016) 125-33.
[24] M.J. McGinity, J.E. Michalek, J.S. Rodriguez, J.R. Floyd, Surgical evacuation of acute subdural hematoma in octogenarians: a ten-year experience from a single trauma center, Br J Neurosurg 31(6) (2017) 714-717.
[25] G. Trevisi, C.L. Sturiale, A. Scerrati, O. Rustemi, L. Ricciardi, F. Raneri, A. Tomatis, A. Piazza, A.M. Auricchio, V. Stifano, C. Romano, P. De Bonis, A. Mangiola, Acute subdural hematoma in the elderly: outcome analysis in a retrospective multicentric series of 213 patients, Neurosurg Focus 49(4) (2020) E21.
[26] A.J. Fowler, T.E.F. Abbott, J. Prowle, R.M. Pearse, Age of patients undergoing surgery, Br J Surg 106(8) (2019) 1012-1018.
[27] D. Peus, N. Newcomb, S. Hofer, Appraisal of the Karnofsky Performance Status and proposal of a simple algorithmic system for its evaluation, BMC Med Inform Decis Mak 13 (2013) 72.
[28] S. Church, E. Rogers, K. Rockwood, O. Theou, A scoping review of the Clinical Frailty Scale, BMC Geriatr 20(1) (2020) 393.
[29] H. Lee, C. Tan, V. Tran, J. Mathew, M. Fitzgerald, R. Leong, T. Kambourakis, D. Gantner, A. Udy, M. Hunn, J.V. Rosenfeld, J. Tee, The Utility of the Modified Frailty Index in Outcome Prediction for Elderly Patients with Acute Traumatic Subdural Hematoma, J Neurotrauma 37(23) (2020) 2499-2506.
[30] C.H. Monsivais D, Kitagawa R, Franch M, Cai C, A retrospective analysis of surgical outcomes for acute subdural hematoma T in an elderly cohort, Interdisciplinary Neurosurgery 14 (2018) 130-134.
[31] R. Raj, E.D. Mikkonen, R. Kivisaari, M.B. Skrifvars, M. Korja, J. Siironen, Mortality in Elderly Patients Operated for an Acute Subdural Hematoma: A Surgical Case Series, World Neurosurg 88 (2016) 592-597.
[32] O.S. Akbik, R.V. Starling, S. Gahramanov, Y. Zhu, J. Lewis, Mortality and Functional Outcome in Surgically Evacuated Acute Subdural Hematoma in Elderly Patients, World Neurosurg 126 (2019) e1235-e1241.
[33] A. Younsi, J. Fischer, C. Habel, L. Riemann, M. Scherer, A. Unterberg, K. Zweckberger, Mortality and functional outcome after surgical evacuation of traumatic acute subdural hematomas in octa- and nonagenarians, Eur J Trauma Emerg Surg (2020).
[34] S.Y. Won, D. Dubinski, N. Brawanski, A. Strzelczyk, V. Seifert, T.M. Freiman, J. Konczalla, Significant increase in acute subdural hematoma in octo- and nonagenarians: surgical treatment, functional outcome, and predictors in this patient cohort, Neurosurg Focus 43(5) (2017) E10.
[35] M. Kaur, P.M. Singh, Current role of dexmedetomidine in clinical anesthesia and intensive care, Anesth Essays Res 5(2) (2011) 128-33.
[36] F. Yakar, E. Egemen, U.A. Dere, E. Celtikci, Y. Dogruel, D. Sahinoglu, I. Cuneyit, B. Bakirarar, E. Adiguzel, E. Coskun, Subdural Hematoma Evacuation via Rigid Endoscopy System: A Cadaveric Study, J Craniofac Surg (2020).

Figure Legends

Figure 1: A flow diagram demonstrating the study selection process

Figure 2: Schematic diagrams adapted from included papers illustrating their operative techniques. Upper panel: Adapted from Yokosuka et al(8). A rigid endoscope and malleable suction catheter are used. Note the bone edges are left aslant (arrow) to maximise manoeuvrability of the instruments in the subdural space. Lower panel: Adapted from Matsumoto et al(13). The part of the haematoma directly under the bone flap is evacuated under direct vision, the underlying brain is protected, before introduction of the rigid endoscope and suction catheter.

Figure 3: Example case taken from Ichimura et al(14). Upper left panel: Pre-operative CT head demonstrating left-sided hyperdense subdural haematoma with midline shift. Upper right panel: Intra-operative photograph illustrating the size of the craniotomy with haematoma immediately evident. Lower left panel: Endoscopic image demonstrating the view during clot evacuation using saline irrigation and suction. Lower right panel: Endoscopic image demonstrating identification and cauterisation of an actively bleeding cortical artery.

Figure 4: Example case taken from Kawasaki et al(11). Upper left panel: Multiple level axial CT images from pre- (upper) and post- (lower) evacuation, demonstrating left-sided ASDH and subsequent removal. Lower left panel: Intra-operative photograph demonstrating the setup in theatre. The assistant holds and operates the flexible endoscope leaving the operating surgeon two hands available to use instruments. Right panel: 3-dimensional CT reconstruction of skull post-operatively, demonstrating the small size of craniotomy employed.

Figure 5: A summary of the factors that require consideration for treatment of the elderly patient presenting with acute subdural haematoma, with possible factors favouring each management option. EAT: Endoscope-assisted technique, DC: decompressive craniectomy, GA: General anaesthetic. Highlighted in red: points of greatest contention

N.B. Table legends within Tables document.

<u>Figures</u>

Figure 1:

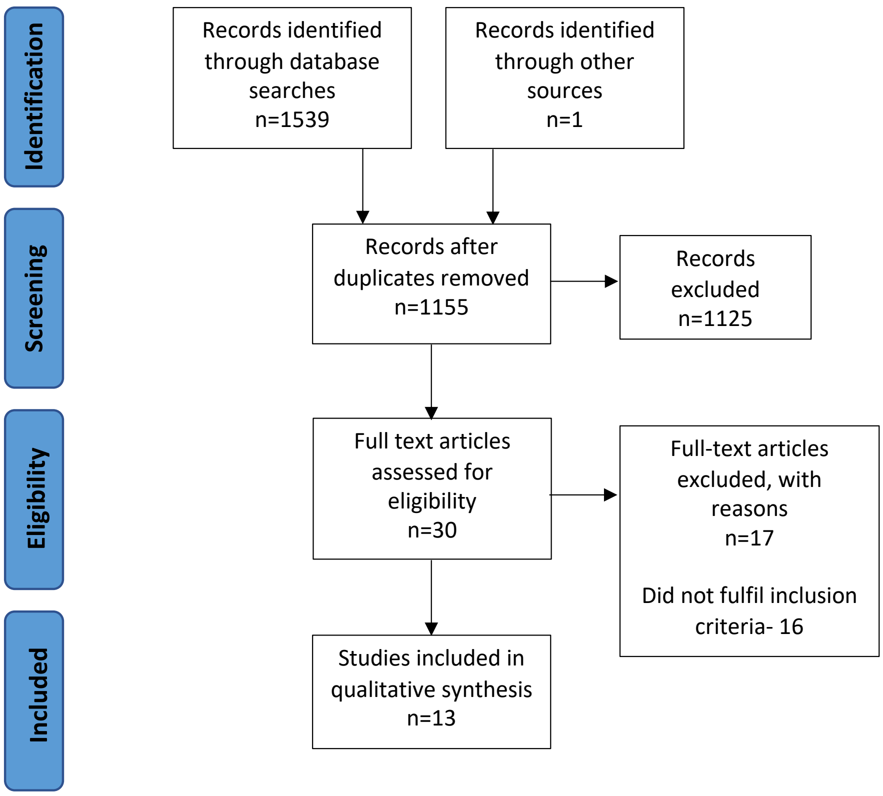

Figure 2:

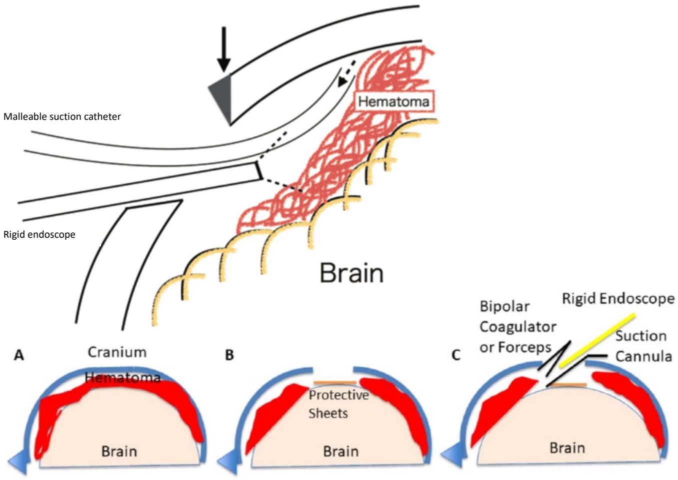

Figure 3:

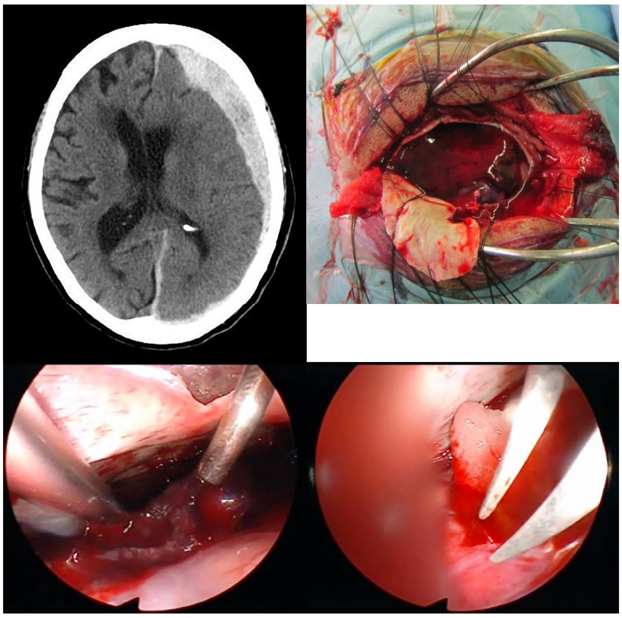

Figure 4:

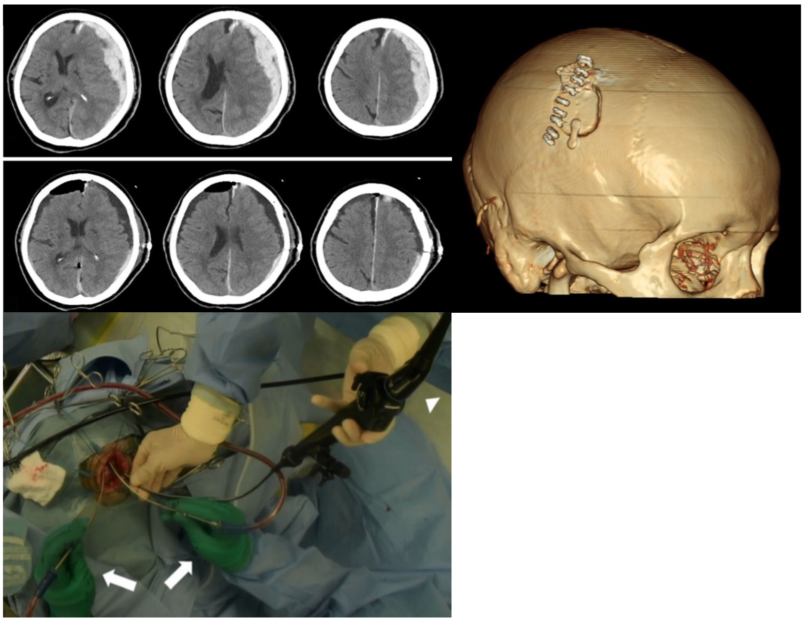

Figure 5:

ASDH in the elderly

Factors to consider
Age
Comorbidities
Pre-morbid functional status
Coagulopathy
Pre-operative neurological status
Adverse imaging features
Suitability for GA
Family wishes

Conservative	MIA	Craniotomy/DC
Advanced Age	Advanced age (>80 years)	Adverse imaging features
Family wishes	Good pre-operative neurological status (reactive pupils, GCS≥9)	Able to tolerate GA
Limited life expectancy	High comorbidity burden (unable to tolerate GA)	Family wishes
Poor pre-operative neurological status	Isolated ASDH	
	Experienced neuro-anaesthetist	

Study	No. of patients	Age (years)	Sex (% male)	Mechanism of Injury	Pre-operative GCS/ pupils	Outcomes	Outcome Time Point
Codd et al (2013) (USA)[6]	1	86	Female	Fall	GCS E1VtM6 PLR intact	Good- 1	Discharge
Kon et al (2013) (Japan)[7]	1	87	Female	Fall	GCS E2V2M4 PLR intact	Good- 1	Discharge
Yokosuka et al (2015) (Japan)[8]	6	75 - 91	50%	Fall- 3; 'Head injury'-1; Unknown- 2	GCS range 6-14 PLR NR	Good- 5 Poor- 1 Death- 0	Discharge
Tamura et al (2016) (Japan)[9]	2	(i) 81 (ii) 73	50%	(i) Fall (ii) Intoxicated fall	(i)GCS 13 deteriorating to 8 (ii)GCS 14, deterioration to absence of PLR	Death- 0. Functional outcome NR	Discharge
Di Rienzo et al (2017) (Italy)[10]	28	76 – 88	57%	Post-traumatic- 22 No history of trauma- 6 anticoagulated patients	GCS range 9-11 PLR intact in 100%	Good- 27 Poor- 0 Death- 1	3 months
Kawasaki et al (2018) (Japan)[11]	15	67 – 93	67%	NR	Median GCS 12 (range 3-15) Absence of PLR in 20%	Good- 8 Poor- 7 Death- 0	Discharge
Maruya et al (2018)	1	70	Male	Intoxicated fall	GCS E1V1M4	Good- 1	Discharge

(Japan)[12]					PLR absent unilaterally		
Matsumoto et al (2018) (Japan)[13]	6	82 – 97	33%	Fall- 6	Median GCS 13 (range 9-14) PLR NR	Good- 5 Poor- 1 Death- 0	Discharge
Ichimura et al (2019) (Japan)[14]	5	82 – 94	80%	Fall- 4; Unknown mechanism- 1	GCS 3-13 PLR NR	Good- 3 Poor- 0 Death- 2	Discharge
Hwang et al (2020) (Rep of Korea)[15]	13	65 – 89	46%	Fall- 6; RTC- 3; Unknown- 4	GCS NR PLR absent in 3 patients	Good- 5 Poor- 5 Death- 3	Discharge
Katsuki et al (2020) (Japan)[16]	15	70 – 101	40%	Fall- 12; Unknown- 3	Median GCS 8 (range 6-15) PLR absent in 4 patients	Good- 4 Poor- 6 Death- 5	6 months
Kuge et al (2020) (Japan)[17]	1	73	Male	Fall. Initially no ASDH, re-presented with ASDH 3 days later	GCS E4V4M6 PLR NR	Good- 1	Discharge
Miki et al (2020) (Japan)[18]	26	Median 84 (IQR 77-89)	44%	Fall- 23; RTC- 1; Unknown- 2	GCS: 4-8: 10 patients 9-12: 5 patients 13-15: 11 patients	Good- 18 Poor (including death)- 8	Discharge

Table 1. A summary of included studies, included patients and their outcomes. GCS: Glasgow Coma Scale; PLR: Pupillary Light Reflex; RTC: Road Traffic Collision; ASDH: Acute Subdural Haematoma; IQR: inter-quartile range; 'Good' outcome refers to Glasgow Outcome Score 4/5 or modified Rankin Score 0-3. NR: Not reported.

Study	Age	Pre-op neurology	Imaging	Comorbidities	Coagulopathy	Suitability for GA
Codd et al (2013) (USA)[6]	1	0	0	0	0	0
Kon et al (2013) (Japan)[7]	1	0	0	1	0	1
Yokosuka et al (2015) (Japan)[8]	0	0	1	0	1	0
Tamura et al (2016) (Japan)[9]	1	1	0	1	1	0
Di Rienzo et al (2017) (Italy)[10]	0	1	0	0	0	1
Kawasaki et al (2018) (Japan)[11]	1	0	1	1	1	1
Maruya et al (2018) (Japan)[12]	0	0	0	1	1	0
Matsumoto et al (2018) (Japan)[13]	1	0	1	0	1	0
Ichimura et al (2019) (Japan)[14]	0	0	1	1	0	1
Hwang et al (2020) (Rep of Korea)[15]	0	0	1	1	1	0
Katsuki et al	0	0	1	1	1	1

(2020) (Japan)[16]						
Kuge et al (2020) (Japan)[17]	1	0	1	1	0	0
Miki et al (2020) (Japan)[18]	0	1	1	0	1	0

Table 2. Eligibility criteria for minimally invasive approach for ASDH evacuation reported in individual studies. Key: 0- Not factored, 1- Factored. GA: General anaesthetic.

Study	Size of craniotomy	Position of craniotomy	Endoscope	Anaesthetic	Bleeding Point	Operative duration (minutes)	Complications
Codd et al (2013) (USA)[6]	2.5cm diameter x2	Anterior and posterior	Rigid 3mm endoscope, 0º VA and rigid 4mm endoscope, 30º VA	GA	Not identified	120	Nil
Kon et al (2013) (Japan)[7]	1.5 cm diameter	Frontal	Rigid endoscope, 0º VA	LA	Arterial	47	Nil
Yokosuka et al (2015) (Japan)[8]	2 - 3cm diameter	Thickest portion of ASDH	Rigid 4mm endoscope, 0º VA	LA	Not identified	85 (mean)	Nil

Tamura et al (2016) (Japan)[9]	NR	Frontal	10mm sheath, rigid 2.7mm endoscope, 0º VA	LA	NR	NR	Nil
Di Rienzo et al (2017) (Italy)[10]	3 – 5cm diameter	Thickest portion of ASDH	Not specified	LA - 23 Sedation - 5	NR	65 (median)	Rebleed: 1 Post-operative seizures: 9 Medical complications: 1
Kawasaki et al (2018) (Japan)[11]	3 x 4cm	Thickest portion of ASDH	Flexible 5mm endoscope	LA - 12 LA to GA - 3	Identified- 5 Not identified- 10	108 (mean)	Rebleed: 0 Development of CSDH: 1 Medical complications: 2
Maruya et al (2018) (Japan)[12]	4cm diameter	NR	Flexible endoscope	GA	NR	150	Nil
Matsumoto et al (2018) (Japan)[13]	3cm diameter	Thickest portion of ASDH	Rigid 4mm endoscope, 0º or 30º VA	Sedation	Arterial- 2 Venous- 1 Not identified- 8	93 (median)	Nil
Ichimura et al (2019) (Japan)[14]	3 x 4cm	Thickest portion of ASDH	Rigid endoscope, 0º or 30º viewing angle	LA - 2 GA - 3	Arterial- 2 Venous- 2 Not identified- 1	NR	Medical complications: 2 Rebleeding NR

Hwang et al (2020) (Rep of Korea)[15]	3 x 4cm	Angle of superior temporal line and coronal suture	Rigid 4mm endoscope, 0º viewing angle	LA - 2 GA - 11	Arterial-4 Venous- 1 Not identified-8	90 (median)	Nil
Katsuki et al (2020) (Japan)[16]	2 – 3cm diameter	Thickest portion of ASDH	Rigid 4mm endoscope, 0º or 30º VA	LA	Arterial- 1 Venous- 2 Not identified-12	91 (median, range 48-156)	Rebleed: 2
Kuge et al (2020) (Japan)[17]	2.5 x 3cm	NR	Rigid endoscope, 0º and 30º VA used	Sedation	Not identified	NR	Nil
Miki et al (2020) (Japan)[18]	3 x 4cm	Thickest portion of ASDH	Rigid endoscope, 0º or 30º viewing angle	GA	NR	111 (median)	Rebleed: 1

Table 3. Surgical factors reported in included studies. NR: Not reported. GA: General anaesthetic, LA: Local anaesthetic; VA: Viewing angle (of endoscope)