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Membranectomy in Chronic Subdural Hematoma: a Meta-Analysis

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Abstract

Objective—Initial management strategies of chronic subdural hematoma (cSDH) are controversial, and range from bedside twist-drill or burr hole drainage, to craniotomy with membranectomy (CWM). We aim to (1) perform a meta-analysis of the available data on the outcomes of CWM for treatment of cSDH in published English-language literature, and (2) evaluate collective outcomes of CWM with respect to morbidity, mortality, and recurrence rates.

Methods—A search of English-language literature performed in PubMed, Ovid, and Cochrane databases using keywords (“subdural hematoma” or “chronic subdural hematoma”) and (“membrane” or “membranectomy”) from inception to December 2016 was conducted. Studies reporting outcomes of CWM in cSDH were included. Mortality, morbidity, follow-up duration, and recurrence rate data were extracted and analyzed. Pooled estimates and confidence-intervals (CIs) were calculated for all outcomes using a random-effects model.

Results—Of 301 articles found, 17 articles containing 5369 patients met our eligibility criteria. Mean follow-up duration ranged from 1–30.8 months. Collective mean mortality and morbidity rates were 3.7% and 6.9*%*, respectively (95% CI 2–5.4% and 2.1–11.6%; p<.001 and p=.004). The collective mean recurrence rate was 7.6% (95% CI: 5%–10.2%; p<.001).

Conclusions—Clinical data on outcomes of CWM in cSDH are limited to single institutional analyses, with considerable variation in recurrence rates and follow-up time. The rates we reported

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Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

are comparable to the 5% mortality and 3–12% morbidity rates, and lower than the 10–21% recurrence rate in the literature for burr holes or craniotomy without membranectomy. This meta-analysis provides an in-depth analysis of available data and reviews reported outcomes.

Keywords

subdural hematoma; membranectomy; neurosurgery; TBI; traumatic brain injury; craniotomy

Introduction

Initial management strategies of chronic subdural hematoma (cSDH) are controversial, and range from medical to surgical interventions. Surgical interventions vary from bedside twist-drill (TD) or burr-hole (BH) drainage, to craniotomy with drain insertion, irrigation, and/or membranectomy (i.e. resection or fenestration of the subdural inner and/or outer membranes).[1] Putnam and Cushing, in 1926, championed craniotomy with outer membrane (CWM) removal in cSDH treatment, despite up to 30% craniotomy mortality.[2] However, CWM is currently only used under conditions of subdural re-accumulation, solid hematomas, or following suboptimal postoperative cortical re-expansion.[3] In its place, BH drainage [4] has become the primary treatment for cSDH, and has been suggested to be superior to CWM due to lower reoperation rates and better postoperative outcomes.[5] The adjunctive use of continuous catheter drainage following BH or TF craniotomy further improved cSDH outcomes [6], particularly when compared to craniotomy alone.[78910,11]

At present, the surgical management of encapsulated subdural hematoma remains unclear as to whether or not the inner membrane should be removed. Arutyunov[12], Gorbatsevich and Shustin [13], Gomez [14], and Umbach [15] recommended that all capsular membrane components (i.e. both the outer *and* inner membrane) be resected, as this may allow for brain re-expansion and reduce the post-operative potential subdural space. However, others [16171819] have recommended simple burr hole evacuation without the need for a craniotomy. To date, a meta-analysis investigating the outcomes associated with CWM has not been published. In this study, we aim to perform a meta-analysis of the available data and evaluate the collective outcomes of craniotomy with membranectomy for treatment of cSDH in the published English-language literature with respect to morbidity, mortality, and recurrence rates.

Material and Methods

A thorough search of published English-language literature was performed in PubMed, Ovid, and Cochrane databases using the keywords (“subdural hematoma” or “chronic subdural hematoma”) and (“membrane” or “membranectomy”) from database inception to December 2016. Each manuscript was reviewed independently by two authors for relevance. The senior author acted as the final mediator if disagreements for inclusion occurred. This study was exempt from Institutional Review Board evaluation due to its investigations of published literature and non-involvement of human subjects. This study was conducted in agreement with the PRISMA guidelines (Preferred Reporting Items for Systematic Reviews and Meta-analyses) statement.[20]

A total of 301 articles were identified and reviewed (Figure 1). Abstracts were screened and case reports, review papers, and studies that didn't specify which patients underwent craniotomy with membranectomy were excluded. 17 articles remained and the full text of each article was independently assessed by two of the authors. Articles were included if they reported treatment outcomes of craniotomy with membranectomy in cSDH patients. Demographic, lesion characteristics and grading, mortality, morbidity, follow-up duration, and recurrence rate data were extracted and analyzed.

The primary outcome variables investigated were morbidity, mortality, and recurrence rates. In each study, morbidity was defined as a major complication, disability, or poor health following surgical intervention, and mortality was defined as death secondary to cSDH or its sequelae. Recurrence was defined as new blood visualized on brain imaging following surgical intervention.

cSDH grading was based on the scheme proposed by Markwalder [3], which defined grade 0 as no neurological deficits; grade 1 as patient alert and oriented with mild symptoms and no neurological deficits; grade 2 as drowsiness or disorientation with variable neurological deficits; grade 3 as stupor with response to noxious stimuli and severe focal neurological signs; grade 4 as coma with no motor response or decerebrate or decorticate posturing. Good pre- and postoperative results were considered grades 0–2 and poor pre- and post-operative results were grades 3–4. Statistical analyses were performed using OpenMeta[Analyst] (Brown University, Rhode Island, USA) using the random effect model. The pooled estimates and 95% confidence intervals (CI) were calculated for primary outcome variables.

Results

After careful examination of the published articles, 17 met our eligibility criteria and were used for qualitative and quantitative analyses containing 5369 patients studied during 1964–2016. A tabulation of the included studies with demographic information and sample size is presented in Table 1. The mean sample size was 568 (range: 34–2275), age ranged from 6–100 years, and the reported mean follow-up duration ranged from 1–30.8 months. Table 1 also presents data on study length, intervention type, number of patients being reoperated on, Glasgow coma score, and presenting symptoms.

Table 2 presents the outcomes of cSDH resection via CWM. The reported mean time from injury to operation was 1–4.4 months, and the post-operative hospital stay ranged from 1–71 days. cSDH grade ranged from one to four. In all studies, the type of membranectomy (e.g. outer vs. inner membranectomy) was extracted when possible. Additionally, the specific surgical intervention was documented. Of note, in 16 of the 17 studies examined, all patients who underwent CWM also had placement of a postoperative drain (as noted in Table 2). In all studies reviewed, no mention of attrition rate was found. The meta-analysis revealed the collective mean mortality rate to be 3.7% (95% CI 2–5.4%; p<.001) (Figure 2). The collective mean morbidity rate was 6.9*%* (95% CI 2.1–11.6%; p=.004) (Figure 3). The collective mean recurrence rate was 7.6% (95% CI: 5%–10.2%; p<.001) (Figure 4).

Discussion

In this study, we analyzed the outcomes of CWM treatment of cSDH on 5369 patients between 1964 and 2016. The ultimate treatment goals for cSDH is complete evacuation with no recurrence following surgical evacuation, while mitigating mortality and morbidity related to the natural history of cSDH and complications secondary to surgical intervention. CWM met these benchmarks for treating cSDH, with lower recurrence rates and similar mortality and morbidity rates to minimally invasive methods over a broad follow-up duration ranging from 1–30.8 months and similar treatment side effects to minimally invasive interventions (i.e. burr hole evacuation). Similar or higher morbidity and mortality rates, and uniformly higher recurrence rates have been reported for burr hole evacuation of cSDH.[21221] The mortality following cSDH evacuation ranged from 0% to 20% in the studies included in this meta-analysis, with a collective mortality rate of 3.7% (95% CI 2–5.4%; p<.001). Morbidity rates were generally higher in the included studies, which corresponds with the 6.9% collective morbidity rate we found (95% CI 2.1–11.6%; p=.004). The majority of studies did not report breakdowns of outcome based on cSDH grade, or standard deviations for age and hospital stay and a meta-analysis of these variables could not be conducted. Furthermore, some studies solely investigated craniotomy with membranectomy or mini-craniotomy with membranectomy while others included burr-hole drainage, and therefore all data extracted had to be broken down by intervention type.

Chronic subdural hematomas are a complex neurosurgical entity with increasing prevalence given the increase in the population at risk. In addition, the use of newer anticoagulant therapy for cardiac and cerebrovascular issues increases the likelihood of the development of a cSDH from minor TBI. The optimal treatment for this has been debated for many years and there are many series describing the main treatment modalities of burr holes and craniotomies.[23242526] Although specific clinical parameters dictate the unique surgical intervention for each individual patient, we recommend the establishment of refined decision-making criteria to guide surgical intervention in cSDH patients. At our institution, the decision-tree used to stratify patients to BH drainage or cSDH is depicted in Figure 5, and is based on surgical paradigms proposed in the cSDH literature.[1359112330] We have focused in this meta-analysis on the experience with CWM, and our analysis was restricted to papers that described CWM. One of the limitations is that this was frequently poorly defined as to whether the membranectomy was of the outer subdural membrane or the inner subdural membrane.

These are different pathologically. The outer membrane is adherent to the dura and vascular in nature with ample amounts of vEGF.[272829] “Stripping” these membranes has been frowned upon in the recent literature because of the tendency for bleeding to occur at the edges from the dura that is exposed.[30] The inner membrane is usually thin and translucent and avascular. This can be adherent to the underlying arachnoid over the cortical surface. When this is microdissected off of the arachnoid it may be fenestrated. This allows the underlying brain to re-expand. Also, there are frequently blood break-down products sequestered between the arachnoid and this membrane. Where possible, in our analysis we identified whether membranectomy referred to the outer or inner subdural membranes. The outer cSDH membrane is highly vascularized and exudation from macrocapillaries is critical

in cSDH enlargement.[31] Fenestration or complete resection of the outer membrane may mitigate rebleeding following cSDH resection, and may facilitate intracranial fluid efflux via the recently elucidated dural lymphatics.[3233] Furthermore, fluid flux through the glymphatic[3435] pathway has been implicated in a variety of intracranial homeostatic and pathological mechanisms, and membranectomy may facilitate the egress and reabsorption of cSDH contents by cortical glymphatic and dural lymphatic pathways.

With an aging population in the United States, the incidence of cSDH is expected to increase. As such, procedures which result in low recurrence rates can positively influence the overall outcomes of cSDH patients. One meta-analyses of 34,829 patients reported 3.5–4% mortality, 7–11% morbidity, and 10.7–11% recurrence rates overall.[36] We demonstrate that CWM results in lower recurrence rates on average, than alternative interventions including craniotomy or BH drainage without membranectomy. Furthermore, the morbidity and mortality rates of CWM are comparable to those reported in the literature for cSDH drainage regardless of intervention type. As such, CWM may decrease the likelihood of cSDH recurrence and secondary intervention, while exhibiting similar morbidity and mortality profiles as other interventions reported in the literature.

There were a number of limitations in this study. The heterogeneous methodology of the published papers in reporting their outcomes limited the ability to perform meta-analysis on all variables. Despite this heterogeneity, each study's methodology was evaluated to determine if differences exist. Heterogeneity of the type of membranectomy (i.e. fenestration or complete resection), and variability of the surgical intervention is a limitation, as studies which utilized a craniotomy or a mini-craniotomy with a membranectomy (regardless of the extent of the membranectomy) were included in the meta-analysis. Several studies had a small sample size, and breakdown of data per patient type was not available. Furthermore, in 16 of the 17 papers included in this meta-analysis, all CWM patients received a postoperative drain. As such, the exact contribution of the membranectomy compared to the postoperative drain in cSDH recurrence remains unclear, and requires further inquiry. This meta-analysis can lay a foundation for future studies to recruit more patients and evaluate differences in surgical intervention with respect to different patient demographics and disease characteristics. In addition, all studies evaluated were case series that did not have control groups. This is an inherent limitation that constrains the conclusions that can be drawn regarding CWM treatment for cSDH. Nonetheless, analysis of the available data in the literature on CWM treatment of cSDH undoubtedly supports the efficacy of this surgical intervention, and offers patients with clinically significant resolution of symptoms while minimizing morbidity, mortality, and recurrence rates. This is the first study to perform a meta-analysis of CWM treatment outcomes for cSDH.

Conclusions

We present data on the outcomes of cSDH resection via CWM in 5369 patients studied during 1964–2016. The meta-analysis revealed the collective mean mortality, morbidity, and recurrence rates to be 3.7%, 6.9*%*, and 7.6%, respectively. The mortality and morbidity rates we report are comparable to the 3.5–5% mortality and 3–12% morbidity rates for burr holes or craniotomy without membranectomy reported in the literature. However, the 7.6%

recurrence rate we report is lower than the 10–21% recurrence rate reported in the literature for burr holes or craniotomy without membranectomy. This suggests that CWM yields a lower likelihood of cSDH recurrence and secondary intervention, while exhibiting similar morbidity and mortality profiles as other interventions reported in the literature.

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Abbreviations

CWM	craniotomy with membranectomy
cSDH	chronic subdural hematoma

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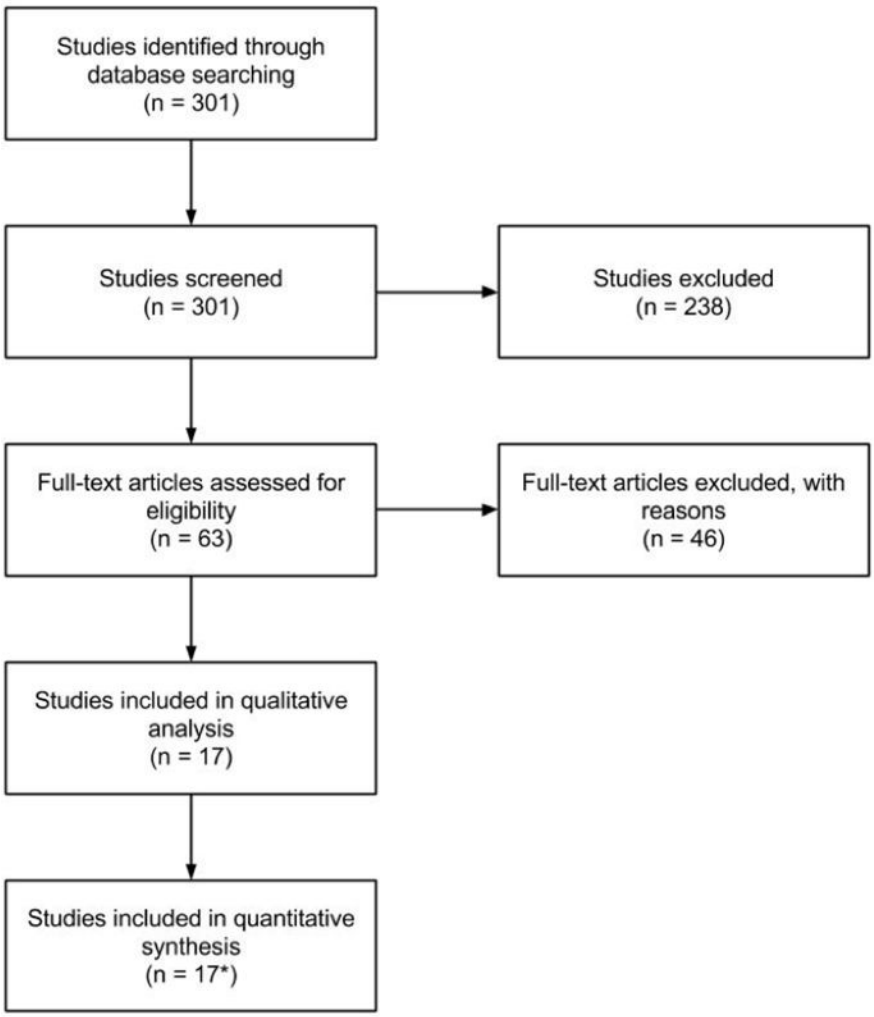

Figure 1.

Flow diagram of study selection.

*12 studies were included in the quantitative analysis of recurrence rates, 8 studies were included in the quantitative analysis of morbidity rates, and 14 studies were included in the quantitative analysis of mortality rates.

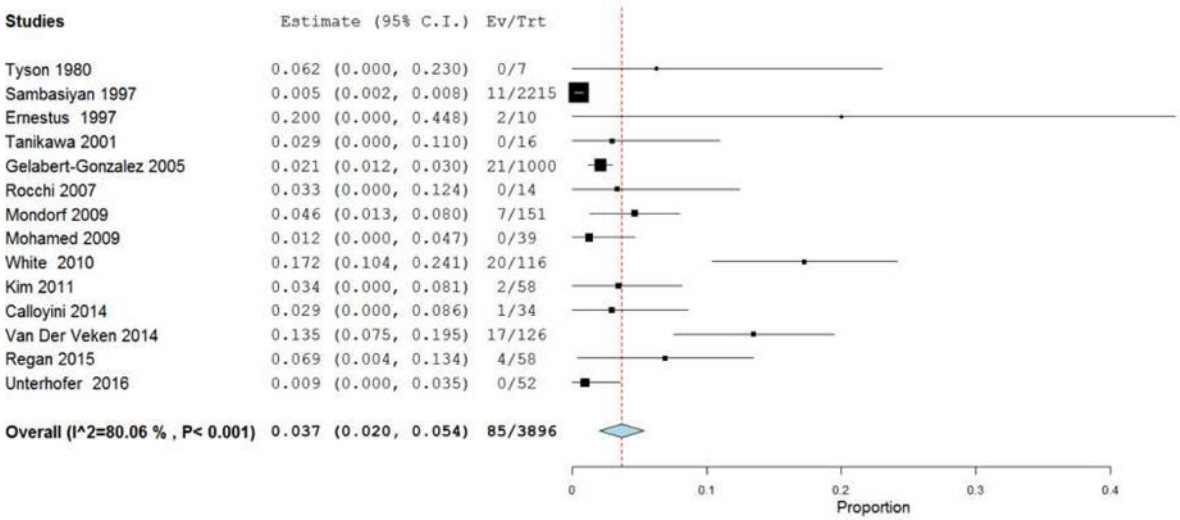

Figure 2.

Forest plot demonstrating a 3.7% overall mortality rate with each line representing the 95% confidence interval. Boxes represent mortality rates in that study with its size correlating to the study's effect size.

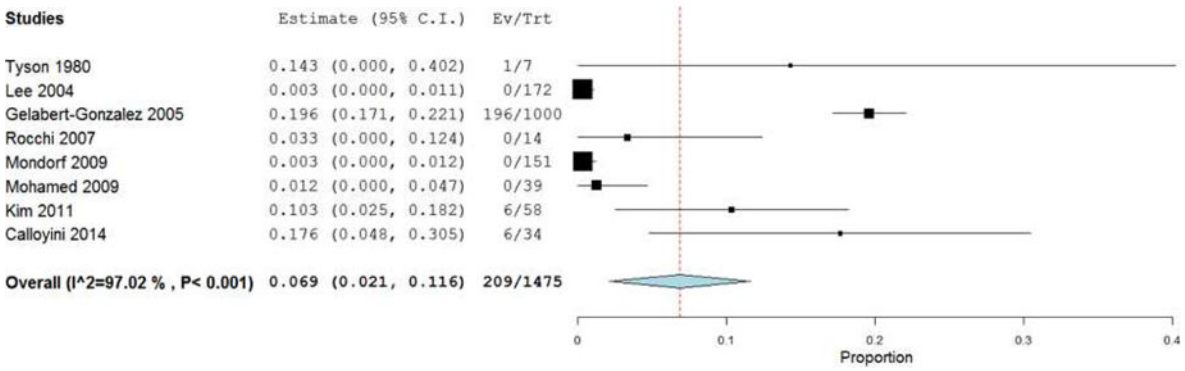

Figure 3.

Forest plot demonstrating a 6.9% overall morbidity rate with each line representing the 95% confidence interval. Boxes represent morbidity rates in that study with its size correlating to the study's effect size.

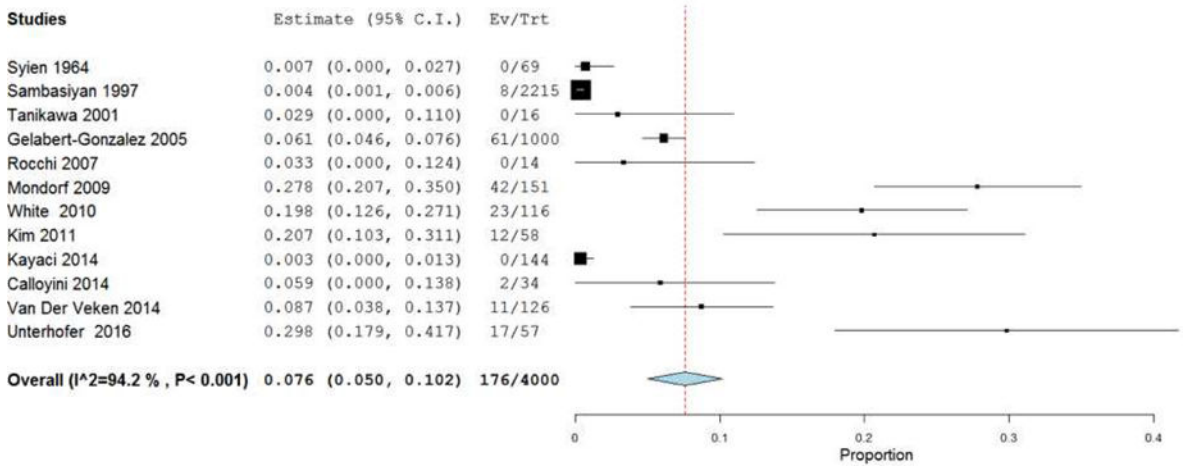

Figure 4.

Forest plot demonstrating a 7.6% overall recurrence rate with each line representing the 95% confidence interval. Boxes represent recurrence rates in that study with its size correlating to the study's effect size.

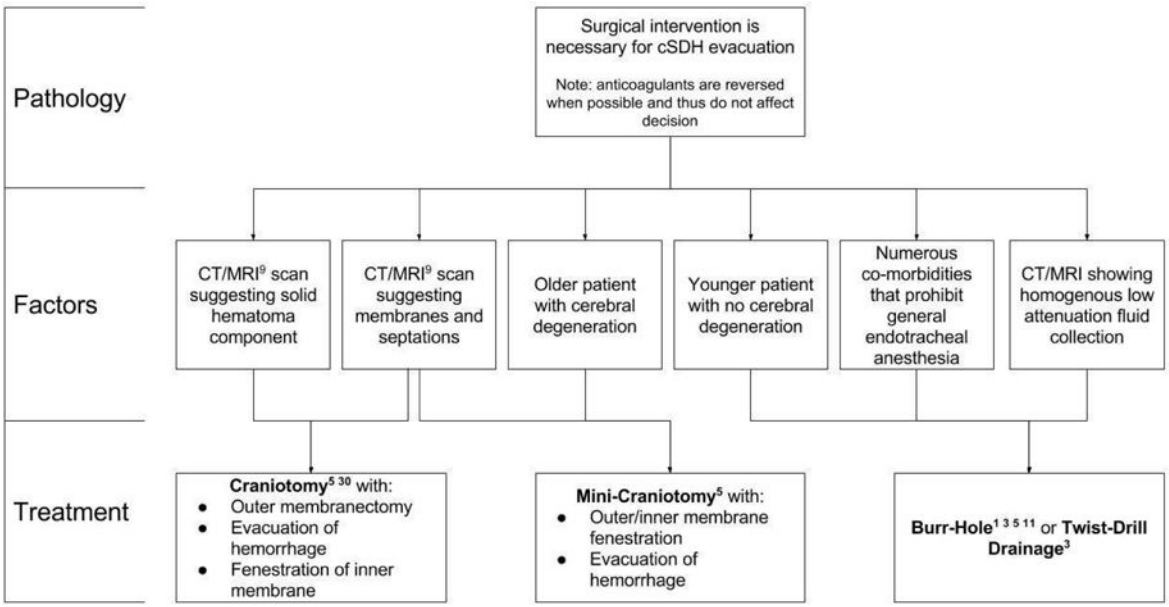

Figure 5.

Decision tree for the type of chronic subdural hematoma (cSDH) evacuation once surgical treatment has been deemed necessary.

Table 1

Details of published studies on outcomes of craniotomy with membranectomy for chronic subdural hematoma.

First Author, Published Year	Institution	Length of Study (years)	Total Sample Size	Intervention Type (n)	Mean age in years (range)	Female (%)	Number of patients with reoperation (%)	Glasgow Coma Score (n)	Presenting symptoms (n)	Comments
Kayaci et al., 2014[37]	Recep Tayyip Erdogan University	7	252	CTIM (144) BCOMI (108)	68.8 ± 1.5 67.6 ± 1.4	27/144 (19%) 30/108 (28%)	N/A	>12(114) < 12 (30) > 12 (90) <12(18)	Mild-moderate head trauma (102/144) Preexisting medical conditions (51/144) Mild-moderate head trauma (84/108) Preexisting medical conditions (39/108)	Preexisting conditions include HTN, DM, and ischemic heart disease (n = 60, 54, and 42 in both groups respectively). Most common symptoms overall were cognitive deficits (64%), hemiparesis (46%), and motor dysphasia (24%).
Callovini et al., 2014[38]	Santo Spirito Hospital	8	34	CR (34)	71 (17-89)	13/34 (38%)	2/34 (6%)	N/A	Headache (14) Altered consciousness (9) Hemisyndrome (15) Aphasia (6) Gait disturbance (9) Seizure (1)	N/A
Lee et al., 2004[30]	University of Cologne, Germany	4	172	CR (134) BH (38)	69 (27-92)	54/134 (40%) 13/38 (34%)	25/134 (19%) 6/38 (16%)	N/A	Headache (67) Hemiparesis (61) Altered consciousness (50)	BH group used two different BHs without membraneectomy (n=38)
Svien and Gelety, 1964[39]	Mayo Clinic	5	69	CR (19)	50 (6-75)	18/69 (26%)	7/19 (37%)	N/A	Headache, Papilledema, bilateral cSDH	BH patients had no membranectomy
Tyson et al., 1980[40]	University of Virginia School of Medicine	6	48	CR (7)	†20–86	N/A	N/A	N/A	N/A	Reoperation occurred 4–8 days postoperatively in four patients with BHs, which were reopened and 50–100 ml of fluid was evacuated. In two cases, a craniotomy was then performed.
Sambasivan, 1997[41]	Medical College Hospital	30	2275	CR (2215) BH (60)	N/A	407/2275 (18%)	11/60 (18%)	N/A	Conscious w/pain (338) Behavioral disturbance (404) Seizures (275) Stroke (670) Coma (343	2215 patients underwent a subtemporalis marsupialization.
Mondorf et al., 2009[42]	Hannover Nordstadt Hospital, Klinikum Hannover	5	193	CR (151) BH (42)	72.5 (26-97)	80/193 (41%	3/193 (2%)	N/A	Hemiparesis (112) Altered consciousness (70) Aphasia (46)	14 deaths due to non-cSDH related pathology
Kim et al., 2011[43]	Seoul Medical Center, Seoul, Korea	8	317	CR (58) BH (259)	59.4 63.7 ± 16.9	12/58 (21%) 68/259 (26%)	12/58 (21%) 23/259 (9%)	N/A	Headache(133) Disturbance of consciousness (89) Motor weakness (68) Gait disturbance (37) Disturbance of consciousness (46) Headache (34) Motor deficits (25) Dysphasia (13)	N/A
Tanikawa et al., 2001[44]	Nagoya City University School of Medicine, Japan	3	49	CR (16) BH (33)	70.3 ± 9.3 69.3 ± 14.9	N/A	0/16 (0%) 4/33 (12%)	N/A	Headache or hemiparesis	N/A
Rocchi et al., 2007[45]	University of Rome La Sapienza, Italy	8	243	CR (14)	62.1 (41-76)	7/14 (50%)	9/14 (64%)	10 (7) 11 (2) 12 (2) 13 (3)	Hemiparesis (12) Aphasia (6) Hyposthenia (2)	N/A

First Author, Published Year	Institution	Length of Study (years)	Total Sample Size	Intervention Type (n)	Mean age in years (range)	Female (%)	Number of patients with reoperation (%)	Glasgow Coma Score (n)	Presenting symptoms (n)	Comments
Gelabert-Gonzalez et al., 2005[46]	Unversity of Santiago de Compostela, Spain	22	1000	CR (1000)	72.7 ± 11.4 (12-100)	372/1000 (37%)	61/1000 (1%)	N/A	Behavioural Distrubance (285) Headache (251) Hemisyndrome (248) Seizures (126) Aphasia (73) Coma (37) Incidental (1)	N/A
Mohamed, 2009[47]	Gezera Hospital, Egypt	12	39	CR (39)	61 (51-73)	14/39 (36%)	0/39 (0%)	> 13 (39)	Contralateral hemiparesis (35) Seizure (1) Headache and fluctuating consciousness (39) Diabetes (3) Hypertensive (2)	N/A
Unterhofer et al., 2016[48]	Medical University of Innsbruck, Austria	2	52	CR (52)	72 (48-89)	13/52 (25%)	14/52 (27%)	N/A	Headache (29)	52 patients but 57 cSDHs
Regan et al., 2015[49]		3	123	CR (58) BH (61)	68 72	19/58 (33%) 25/61 (41%)	14/58 (24%) 4/61 (7%)	§13.6 §14.5	N/A	N/A
Van Der Veken et al., 2014[50]	University Hospital UZ Brussel, Belgium	6	131	CR (126)	73.4	40/126 (32%)	11/126 (9%)	N/A	Motor deficit (36) Altered consciousness (33) Headache(23) Dysphasia (15) Gait disturbance (14) Seizure (5)	N/A
White et al., 2010[51]	Institute of Neurological Sciences, Southern General Hospital-Glasgow, United Kingdom	3	268	CR (116) BH (130)	73 63	N/A	N/A	50/116 show improvement 56/130 show improvement	N/A	N/A
Ernestus et al., 1997[52]	Department of Neurosurgery, University of Cologne-Cologne, Germany	3	104	CR (10) BH (94)	*69 (22-94)	35/104 (34%)	1/8 (13%) 17/92 (18%)	N/A	Headache(39) Psychomotor disturbance (21) Seizure (6) Hemisyndrome (39) Aphasia (21) Anisocoria (10)	BH = Burr Hole Craniostomy

Abbreviations: BCOMI = burr hole with craniotomy and membrane incision; BH = burr hole; CR = craniotomy; CTIM = catheterization and tearing of inner membrane; NA = not available; HTN = hypertension; DM = diabetes mellitus.

*Median was reported instead of mean

†Range reported instead of mean

§Average GCS reported

Table 2

Treatment outcomes of craniotomy with membranectomy for chronic subdural hematoma.

First Author, Published Year	Intervention Type (n)	Average time from injury to operation	CSDH Grade (n)	Outer vs. Inner membranectomy	Drainage	Average follow up in months	Mortality (%)	Morbidity (%)	Recurrence (%)	Post-op duration in days	Major Complications (n)
Kayaci et al., 2014[37]	CTIM (144) BCOMI (108)	N/A	1 (84) 2 (42) 3 (12) 4 (6) 1 (60) 2 (30) 3 (12) 4 (6)	Inner Outer	CSD (144) CSD (108)	12	N/A	N/A	0/144 (0%) 9/108 (8%)	7 ± 0.1 8.8 ± 0.2	N/A
Callovini et al., 2014[38]	CR (34)	N/A	0 (19) 1 (5) 2 (7) 3 (3)	Outer	CSD (34)	N/A	1/34 (3%)	6/34 (18%)	2/34 (6%)	N/A	Subarachnoid hemorrhage (1) Stroke (2) Hygroma (1) Cardiopulmonary (2)
Lee et al., 2004[30]	CR (134) BH (38)	N/A	0 (41) 1 (77) 2 (43) 3 (2) 4 (9)	N/A	CSD (134) CSD (38)	N/A	8/172 (5%)	0/172 (0%)	N/A	N/A	Subdural empyema (2)
Svien and Gelety, 1964[39]	CR (19)	4–7 weeks (*10 days – 1 year)	N/A	N/A	Penrose drain (19)	3	5/69 (7%)	3/69 (4%)	0 (0%)	N/A	N/A
Tyson et al., 1980[40]	CR (7)	4.4 months	N/A	N/A	CSD (7)	22.5	0 (0%)	1/7 (14%)	N/A	N/A	Severely disability (1)
Sambasiv an, 1997[41]	CR (2215) BH (60)	N/A	N/A	Inner N/A	CSD (2215) CSD (60)	18	11/2215 (.5%) 2/60 (3%)	N/A	8/2215 (.4%) 11/60 (18%)	N/A	N/A
Mondorf et al., 2009[42]	CR (151) BH (42)	N/A	N/A	Inner	CSD (151) CSD (42)	N/A	7/151 (5%) 1/42 (2%)	0/193 (0%)	42/151 (28%) 6/42 (14%)	N/A	Seizures (14)
Kim et al., 2011[43]	CR (58) BH (259)	N/A	0 (24) 1 (28) 2 (4) 3 (0) 4 (2) 0 (202) 1 (26) 2 (5) 3 (5) 4 (21)	Outer and inner N/A	subdural CSD (58) CSD (259)	6	2/58 (3%) 21/259 (8%)	6/58 (10%) 38/259 (15%)	12/58 (21%) 23/259 (9%)	Small CR: 35.6 ± 16.5 Large CR: 33.1 ± 14.5 BH: 35.2 ± 21.9	ICH (1) Seizures (2) Pneumonia (3) Infection, pneumocephalus, epidural hematoma, & seizure (9) Pneumonia & sepsis (29)
Tanikawa et al., 2001[44]	CR (16) BH (33)	N/A	0 (12) 1 (3) 2 (1) 0 (21) 1 (6) 2 (4) 3 (1)	Outer and intrahematomal N/A	CSD (16) CSD (33)	6	0/16 (0%) 1/33 (3%)	N/A	0/16 (0%) 4/33 12%)	16.8 ± 3.6 22.4 ± 15.1	N/A
Rocchi et al., 2007[45]	CR (14)	3.5 weeks	N/A	N/A	CSD (14)	30.6	0/14 (0%)	0/14 (0%)	0/14 (0%)	12	0
Gelabert-Gonzalez et al., 2005[46]	CR (1000)	N/A	N/A	N/A	CSD (1000)	N/A	21/1000 (2%)	196/1000 (20%)	61/1000 (6%)	7.9 (range: 3–51)	Epilepsy (62) Intracranial hypotension (9) Subdural empyema (7)

First Author, Published Year	Intervention Type (n)	Average time from injury to operation	CSDH Grade (n)	Outer vs. Inner membranectomy	Drainage	Average follow up in months	Mortality (%)	Morbidity (%)	Recurrence (%)	Post-op duration in days	Major Complications (n)
											ICH (4) Peneumocephalus (2) Pneumonia (22) Thromboembolic complications (8) Cardiac issues (11) Sepsis (10)
Mohamed, 2009[47]	CR (39)	N/A	N/A	Outer	Subgaleal suction drainage (39)	3	0 (0%)	0 (0%)	N/A	N/A	Agitation and delirium (5) 47Seizure (2) 47Chest infection (3)
Unterhofe r et al., 2016[48]	CR (52)	6.5 weeks (*1–20 weeks)	0 (12) 1 (29) 2 (15)	Inner (28)	Subdural Jackson-Pratt (52)	3–6 weeks	0 (0%)	N/A	17/57 (30%)	N/A	Acute subdural bleeding (2) Acute subdural hematoma (1) Seizure (1)
Regan et al., 2015[49]	CR (58) BH (61)	N/A	N/A	Outer	Subdural CSD (58) Subdural CSD (61)	No long term follow-up	4/58 (7%) 2/61 (3%)	N/A	N/A	10.3 7.3	CR (32/58) Seizure (3) Acute stroke (4) New onset arrhythmia (1) Acute intracranial hemorrhage (10) Deep vein thrombosis/pulmonary embolism (1) Myocardial infarction (1) Respiratory failure (3) Pneumonia (4) Uncomplicated UTI (3) Superficial wound infection (1) BH (13/61) Seizure (1) Acute stroke (2) New onset arrhythmia (1) Acute intracranial hemorrhage (2) Deep vein thrombosis/pulmonary embolism (2) Myocardial infarction (1) Respiratory failure (1) Uncomplicated UTI (2) Cellulitis (1)
Van Der Veken et al., 2014[50]	CR (126)	N/A	0 (72) 1 (29) 2 (5) 3 (3) 4 (0)	Outer	Subdural Jackson Pratt (126)	123.5 weeks (2.6–440 weeks)	17/126 (13%)	N/A	11/126 (9%)	15.4 ± 12.5	43/126 Pulmonary infection (24) UTI (9) Decubitus wound (1) Deep venous thrombosis (1) Wound infection (2) Seizure (4) Pneumocephalus (1) Intracerebral hemorrhage (1)
White et al., 2010[51]	CR (116) BH (130)	N/A	N/A	N/A	CSD (116) CSD (130)	3	20/116 (17%) 10/130 (8%)	N/A	23/116 (20%) 23/130 (18%)	N/A	CR Seizure (10) Subdural empyema (3) BH Seizure (12) Subdural empyema (2)
Emestus et al., 1997[52]	CR (10) BH (94)	N/A	0 (5) 1 (2) 2 (1) 0 (38) 1 (30) 2 (15) 3 (9)	N/A	CSD (10) CSD (94)	N/A	2/10 (20%) 2/94 (2%)	N/A	N/A	Median: 14 days range:1–71 days	N/A

Abbreviations: BCOMI = burr hole with craniotomy and membrane incision; CR = craniotomy; ICH = intracerebral hematoma; NA = not available; CSD = closed system drainage.

* Range reported