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Management of Subdural Hematomas: Part II. Surgical Management of Subdural Hematomas

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Abstract

Purpose of review Management of patients with subdural hematomas starts with Emergency Neurological Life Support guidelines. Patients with acute or chronic subdural hematomas (SDHs) associated with rapidly deteriorating neurologic exam, unilaterally or bilaterally dilated nonreactive pupils, and extensor posturing are considered imminently surgical; likewise, SDHs more than 10 mm in size or those associated with more than 5-mm midline shift are deemed operative.
Recent findings While twist drill craniostomy and placement of subdural evacuating vport system (SEPS) are quick, bedside procedures completed under local anesthesia and appropriate for patients with chronic SDH or patients that cannot tolerate anesthesia, these techniques are not optimal for patients with acute SDH or chronic SDH with septations. Burr hole SDH evacuation under conscious sedation or general anesthesia is an analogous technique; however, it requires basic surgical equipment and operating room staff, with a focus on a closed

system with burr hole followed by rapid drain placement to avoid introduction of air into the subdural space, or multiple burr holes with extensive irrigation to reduce pneumocephalus and continue SDH evacuation via drain for several days. Acute SDH associated with significant mass effect and cerebral edema requires aggressive decompression via craniotomy with clot evacuation and frequently a craniectomy. Chronic SDHs that fail conservative management and progress clinically or radiographically are addressed with craniotomy with or without membranectomy.

Summary Surgical SDH management is variable depending on its characteristics and etiology, patient's functional status, comorbidities, goals of care, institutional preferences, and availability of specialized surgical equipment and adjunct therapies. Rapid access to surgical suites and trained staff to address surgical hemorrhages in a timely manner, with appropriate post-operative care by a specialized team including neurosurgeons and neurointensivists, is of paramount importance for successful patient outcomes. Here, we review various aspects of surgical SDH management.

Indication for surgical interventions

While asymptomatic subdural hematomas (SDHs) are treated conservatively, SDHs that result in worsening clinical symptoms or exhibit radiographic evidence of significant mass effect are managed surgically (Fig. 1). SDH recurrence is defined as a re-accumulation of SDH that becomes symptomatic, requiring intervention. SDHs requiring immediate attention are associated with acute clinical deterioration, e.g., mental status changes, unilateral or bilateral dilated pupils, or extensor posturing consistent with brainstem herniation. Although not imminently surgical, SDHs causing more than 5-mm midline shift or over 10 mm in size are considered operative, in principle. Surgical approaches to SDH treatment include twist drill craniostomy, including subdural evacuating port system (SEPS), burr hole(s) allowing for active or passive drainage with or without irrigation and drain placement, craniotomy to span the extent of SDH and allow for membrane removal with bone replaced at the end of surgery, or decompressive hemicraniectomy for acute SDH with significant mass effect
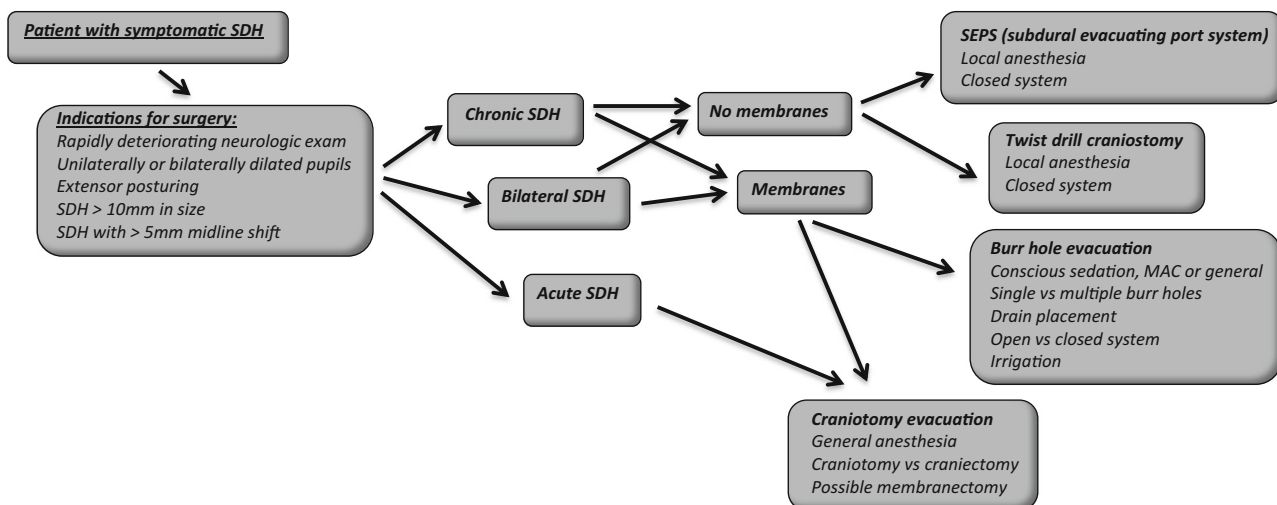

Fig. 1. Surgical management of SDH.

and cerebral edema, while keeping the bone off to allow for cerebral edema resolution.

Twist drill craniostomy

Twist drill craniostomy (TDC) for chronic SDH was described in 1960; the use of closed drainage system was trialed in late 1970s (Table 1). Analogous pediatric procedures (not discussed) include percutaneous tapping and subdural shunt placement [1–4]. TDC variations introduced over time include a variety of drilling angles, craniostomy entrance points, mechanical vs automated drilling, insertion of hollow screws, cannulas or trocars with closed suction systems, and attachment of irrigation ports. TDC complication rates are low and include infection, seizures, and SDH re-accumulation, less commonly serious conditions, e.g., tension pneumocephalus [5, 6]. Other studies report 8% complications [7], including development of new acute SDH/EDH requiring surgical evacuation due to damaged dural/cortical artery or bridging veins, or violation of brain parenchyma by improper drain placement [8, 9]. SEPS introduced in 1999 resulted in clinical outcome improvement and reduced side effects associated with drain placement; a hollow port with self-tapping threads is introduced over the thickest SDH portion without entering the subdural space, allowing for slow drainage via mild negative pressure [10–12]. Neal et al. reported a 77.8% success rate with SEPS, less likely with mixed density or septated SDH [13]. Miele et al. concluded that the degree of head elevation does not affect drainage or recurrence [14]. An RCT by Sindou et al. showed similar success rates with 48- vs 96-h drainage, with twice complications (26.9%) and mortality (11.4%) with longer drainage [15]. A study of older SDH patients by Miranda et al. (> 65 years, mean 80) demonstrated a ~ 10% recurrence with TDC and 26.5% 6-month mortality [16]. Escosa et al. reported closed drain system to be beneficial, while presence of post-operative midline shift > 5 mm, SDH > 10 mm and neurologic deficits were associated with recurrence, regardless of dexamethasone, aspirin, or AC use [17]. Krieg et al. reported a 63.3% success with hollow screws; 16.2% patients required repeat screw placement and 20.5% required burr holes with membranectomy [18].

TDC under local or monitored anesthesia care (MAC) may be optimal in older patients with comorbidities; bilateral SDH drainage is accomplished without position change. Yadav et al. proposed modified angle TDC, using an infant feeding tube over guidewire for drain placement to avoid violating parenchyma [19]. Balser et al. compared the time to intervention and length of stay with SEPS vs burr holes, confirming that TDC is rapid and safe [20]; other studies suggest shorter procedure times but longer drainage with TDC [21]. SDH entry site and continued drainage may play a role. Jablawi et al. reported 67% effectiveness with TDC, 43% patients requiring open evacuation; entry points were over thickest SDH width rather than along the superior temporal line 1 cm anterior to the coronal suture, and scalp incision was closed without drain placement [22]. Further modifications include irrigation ports allowing instillation of adjunct therapies into SDH cavity. Wang et al. reported SEPS-like system with two ports, one for drainage and one for irrigation [23]. Neils et al. evaluated intra-cavity tPA with TDC, reporting 0% recurrence with tPA vs 30% without tPA; the mean drainage volume increased from 90 to 427.33 cm^3 [24]. Urokinase likewise decreased duration of indwelling drain and hospital stay, with 0.43% recurrences [25]. Traumatic brain injury (TBI) causes tissue plasminogen activator release, increased plasmin levels, activation of fibrinolysis, inflammatory response, and increased vascular permeability via kallikrein system; tranexamic acid (TXA) counteracts this by binding to lysine sites on plasminogen with a decrease in plasmin levels [26]. The use of oral TXA 650 mg daily as SEPS adjunct resulted in a ~ 40.74% SDH reduction upon SEPS placement, with an additional 91.31% with continued TXA [27].

Burr hole evacuation

Over 700 articles and 25 clinical trials are published on burr hole SDH evacuation (BHE) (Table 2). OR environment is required due to need for perforator drills, electrocautery, and other surgical instruments; the remainder is flexible to tailor to patient needs. The standard burr hole diameter (14 mm) allows for larger dural opening, better visualization of clot and membranes, easier access to control bleeding, and possible introduction of additional instruments, e.g., endoscopes. While TDC introduces minimal air due to small cranial opening and closed drainage, BHE allows significant air into SDH space, requiring irrigation and drain placement for evacuation.

Anesthesia

Similar to TDC, BHE can be performed under local or MAC. Khadka et al. described BHE under local anesthesia with 98.6% evacuation and 4.7% recurrence [28].

Table 1. Twist drill craniostomy studies

Author	Type	Number of patients	Outcomes	Complications
Tabaddor, Shulmon 1977	Observational, closed system	21 pt, chronic, subacute SDH	Closed system: groups 1–4: intact, lethargic, stuporous, or comatose; 1/21 unchanged, 18/21 improved, 2 deaths	2 deaths in closed drainage group
Hubschmann 1980	Observational, closed drain	22 pt	18/22 improved, 1/22 required repeat twist drill, 1/22 required craniotomy, 2/22 failed	1/22 re-accumulated
Carlton, Saunders 1983	Prospective, closed system	9 pt	9/9 improved, 7/9 cured	None
Camel, Grubb 1986	Retrospective, closed system	114 pt	102/114 successful, 98/114 improved, 7/114 no improvement; 12/114 additional procedures, 9/114 death	12/114 additional procedures; 9/114 mortality; no infections
Rychlicki et al. 1991	Retrospective case series, closed system	65 pt	63/65 improved, 2/65 no improvement	None
Vilalta et al. 1991	Retrospective, closed drain	68 pt: 36 cSDH, 6 saSDH, 22 mix, 4 aSDH	12/68 comatose on admission, 12/68 required repeat, 6/68 deaths	
Smely et al. 1997	Prospective	66 pt, 33/66 twist drill 33/66 burr hole	Twist drill: 6/33 recur, 2/33 deaths Burr hole: 11/33 recur, 6/33 recur twice; 3/33 deaths	Twist drill no infection; burr hole 6/33 infections
Reinges et al. 2000	Prospective	118 pt, twist drill w/ tapping	25/118 × 1 tap, 30/118 2 × tap, 21/118 × 3 tap, 16/118 × 4 tap, other 27/118 more than 4; 92/118 cured by < 5 taps; 7/118 no improvement	11/118 new acute SDH, 2/118 SDH empyema
Williams et al. 2001	Retrospective	62 pt: 11/62 twist drill drain, 37/62 burr hole, 14/62 burr hole drain	7/11 twist drill pt deteriorated, 6/37 burr hole pt deteriorated, 1/14 burr hole plus drain deteriorated	7/11 twist drill needed redo, 4/37 burr hole required redo, 1/14 burr hole plus drain got redo
Miele et al. 2005	Retrospective	42 pt: 24/42 HOB flat, 20/42 HOB up to 30 degrees; closed drains	Elevated HOB 239 cm^3 drainage, HOB flat 166 cm^3 drainage; 41/42 improved; 13/42 complication; recurrence in 9/24 flat, 7/20 HOB up in relation to coagulopathy	2/42 small aSDH; 6/42 pneumocephalus; 16/42 required repeat procedure not related to flat
Muzli et al. 2005	Prospective RCT	47 pt, 22 SEPS, 24 burr hole, irrigation, closed drain	Recurrence, mortality, recovery similar; at 2 months 14/22 SEPS showed SDH resolution; 8/24 burr hole group showed resolution	
Horn et al. 2006	Prospective based on preference	79 pt; 55/79 twist drill, 24/79 burr hole vs crani	10/55 twist drill group required reoperation; 2/24 burr hole vs crani required reoperation; 4/55 death in twist drill group, 3/24 death in burr hole vs crani group	Twist drill: 3/55 aSDH, 2/55 required shunt, 1/55 seizure, 1/55 sepsis Burr hole vs crani: 1/24 wound, 1 aSDH, 1 subdural shunt,1 stroke, 2 worsening AMS
Ramnarayan et al. 2008	Retrospective	42 cSDH	37/42 improved at 1 week	
Gokmen et al. 2008	RCT	70 pt, 32/70 burr hole, 38/70 twist drill	2/32 burr hole group recurred; 1/38 twist drill group recurred	2/70 deaths, 1/70 CN VI palsy
Sindou et al. 2010	Prospective RCT	65 pt; twist drill, closed drain	35/65 48 h vs 30/65 96 h of drainage; 4/35 48 h group vs 3/30 96 h of group recurrences; 5/65 death	5/65 death
Rughani et al. 2010	Case control, SEPS	129 pt, 28 SEPS, 57 burr hole, 44 craniotomy	7/28 SEPS pt vs 8/57 burr hole pt required additional procedures; 2/28 SEPS pt vs 3/57 burr hole pt died	2/28 SEPS pt vs 3/57 burr hole pt died
Ibrahim et al. 2010	RCT	65 pt; twist drill, 35/65 48 h vs 30/65 96 h duration	~85% clinically improved in each group; 120 cm^3 48 h duration, 285 cm^3 96 h duration of drainage	Complications 10.7 vs 26.9%, 3.8 vs 11.4% death
Miranda et al. 2011	Retrospective review	209 pt, 44 twist drill, 21 burr holes, 72 cranies	4/44 twist drill recurred, 1/21 burr hole recurred; 35/209 died in the hospital; decadron used	

Table 1. (Continued)

Author	Type	Number of patients	Outcomes	Complications
Escosa et al. 2011	Retrospective	312 pt; twist drill with drain, decadron	37/312 pt recurred; 1/312 due to ruptured AVM ≥ deteriorated; 3/312 death prior to discharge	22/312 insignificant aSDH within SDH; 3/312 aSDH, 5/312 parenchymal damage by catheter
Lin et al. 2011	Retrospective	448 pt, 178 twist drill, 270 burr hole with irrigation	Twist drill: 158/178 cured, 14/178 recurred ≥ repeat evacuation; burr hole: 204/270 cured, 32/270 recurred ≥ repeat OR	14/178 twist drill complications (all recurrences), 56/270 burr hole complications (4 infection, 6 tension pneumocephalus, 5 parenchymal injury, 9 seizure, 32 recurrence)
Neils et al. 2012	Retrospective	139 pt; 85 twist drill, 12 twist drill + tPA; 54 burr hole, 3 burr hole + tPA	30% recurrence twist drill ≥ 0% with tPA; 11.8% recurrence with burr hole ≥ 0% with tPA	None
Lee et al. 2012	Retrospective	134 pt, twist drill	114/134 (85.1%) improved; recurrence 8/134 (5.6%)	2/134 epidural catheter placement
Neal et al. 2013	Retrospective, SEPS	159 pt with 171 SDH	133/171 successful drainage at the time of placement, 76% success on delayed scan	1 pt required emergent craniotomy post SEPS
Balser et al. 2013	Retrospective	29 pt twist drill, 44 pt burr holes	4/29 twist drill and 4/44 burr hole patients required reoperation, 14 vs 9%	0 death, 0 aSDH, 0 parenchymal IPH
Yadav et al. 2013	Prospective	50 pt; modified twist drill w/infant feeding tube; various positions	7/50 (14%) inadequate evacuation ≥ burr hole	1/48 (2.4%) catheter failure
Kim et al. 2014	Retrospective	65 pt, 48 twist drill, 17 burr hole drainage	42/48 (87.5%) twist drill and 13/17 (76.4%) improved; 4/48 (8.33%) twist drill recurred, 5/17 (29.4%) burr hole recurred	No deaths; 1/202 developed IPH/SAH, 9/202 pneumocephalus
Lu et al. 2015	Retrospective	202 pt, twist drill, urokinase	193/202 (95.5%) improved, 8/202 failed to improve; recurrence rate 0.43%	Twist drill: 1/68 contusion, 9/68 pneumocephalus; burr hole: 3/53 acute SDH or EDH; 3/53 pneumonia, 46/53 pneumocephalus
Wang et al. 2016	Observational retrospective	121 pt; 68 twist drill with YL-1 needle; 53 burr hole with irrigation	68/68 twist drill, 50/53 neurologically improved; 9/68 (13.2%) twist drill recurred ≥ 4 (5.9%) redo, 9/53 (17%) burr hole recurred ≥ 4 (7.5%) redo	6/68 minimal hematomas w/twist drill; 0 deaths
Lee et al. 2016	Retrospective	86 pt; 68 twist drill SEPS, 18 burr hole	All improved post op; 2/68 twist drill recurrence, got burr hole	Twist drill: 1/38 wound infection, 1/38 pneumonia; burr hole 1/45 intracranial infection, 1/45 seizures, 1/45 pneumonia
Wang et al. 2017	Prospective	38 twist drill, 45 burr hole	7/38 (18.4%) twist drill recurred, 5/45 (11.1%) burr hole recurred	3/67 EDH, aSDH, and IPH
Min et al. 2017	Retrospective	74 pt b/l SDH; 67 twist drill, 6 burr hole, urokinase	62/67 improved; 8/74 had recurrence	1/387 twist drill induced aSDH requiring craniotomy
Jablawi et al. 2017	Retrospective	233 pt, 253 cSDH, 387 twist drill Tx; no drain placed	260/387 (67%) successful twist drill procedures; 133/233 cured; 127 (33%) twist drill failed in 100 (43%) pt requiring open surgery	

Table 2. Burr hole craniotomy studies

Author	Type	Number of patients	Outcomes	Complications
Tabaddor and Shulmon 1977	Observational, multiple burr holes with drainage	22 pt, chronic, subacute SDH	Groups 1–4: intact, lethargic, stuporous or comatose; 3/22 unchanged, 9/22 improved, 5/22 deteriorated, 5/22 deaths	5 deteriorated, 5 deaths
Weir 1983	Observational	71 pt, chronic	46/71 red rubber catheter, 23/71 closed system	
Tsutsumi et al. 1997			3.1% with drain, 17% without	
Laumer et al. 1989	Clinical trial	144 pt, burr holes	Closed drain, no drain vs Rickham w/ aspiration	
Wakai et al. 1990			5% recurrence with drain, 33% no drain	
Hamilton et al. 1993	Observational, burr hole vs crani	92 pt	49/92 crani, 43/92 burr hole with similar outcomes; 8/92 required reoperation; 2/92 death at d/c	
Kitakami et al. 1995	Prospective	19 pt, burr hole, irrigation, CO2	1/19 recurred (5.3%)	None
Tsutsumi et al. 1997	Prospective	199 pt, 230 SDH, all chronic	3.1% recurred with closed drain, 17% no drain; 3.4% (1.1 vs 11.1%) recurred in MRI T1 high group, 11.6% (8.1 vs 23.1%) not high	None reported
Smely et al. 1997	Prospective	66 pt, 33/66 twist drill, 33/66 burr hole	Twist drill: 6/33 recur, 2/33 deaths Burr hole: 11/33 recur, 6/33 recur twice; 3/33 deaths	Twist drill no infection; burr hole 6/33 infections
Hennig, Kloster 1999	Prospective	77 pt burr hole irrigation, 55 pt burr hole no irrigation, 9 pt craniotomy	2/77 (2.6%) recurred with irrigation; 15/46 (32.6%) burr hole no drain; 5/21 (23.8%) burr hole with drain; 4/9 (44.4%) with craniotomy	9 required reoperation; 3 empyema in burr hole group; 5 deaths due to aSDH, empyema
Nakaguchi et al. 2000	Prospective	135 pt treated, 63 pt catheter tip analyzed	16 (13%) recurred, SDH at 7 days <10 mm 12% vs >10 mm 45% recurrence; SD air 8% recurrence with none, 26% with 5%, 48% with 30%, drain tip: frontal 5%, parietal 38%, occipital 36%, temporal 33% recurrence	12 (10%) re-operated
Kwon et al. 2000	Retrospective, burr hole, closed system	175 pt, 145/175 had burr holes	150–413 cm³ drained off; 6/145 recurred; 81/145 drained >200 cm³ with 0 recurrences, 94/145 drained <200 cm³ 6/145 recurrences	
Williams et al. 2001	Retrospective	62 pt, 11/62 twist drill w drain, 37/62 burr hole, 14/62 burr hole w/drain	7/11 twist drill pt deteriorated, 6/37 burr hole pt deteriorated, 1/14 burr hole plus drain deteriorated	7/11 twist drill needed redo, 4/37 burr hole required redo, 1/14 burr hole plus drain got redo
Kuroki et al. 2001	Prospective	56 pt burr hole closed drain, 45 pt burr hole, irrigation, drain	All patients improved; 1/56 (1.8%) strict closed drain recurred, 5/45 (11.1%) irrigation group recurred	
Hirashima et al. 2002	Prospective	48 pt burr holes; 12 pt etizolam (9 pt withdrew), 24 pt control	0/12 etizolam group recurred; 7/24 (29.2%) controls recurred, 5 re-operated	12/24 etizolam group somnolent, 9 withdrew
Konig et al. 2003	Retrospective	114 pt, 95 burr hole, 14 craniotomy	46/114 improved GCS; 92/114 GCS >13; 17.5% recurrence rate	4/114 (3.5%) death
Muzli et al. 2005	Prospective RCT	47 pt, 22 SEPS, 24 burr hole with irrigation, closed drain	Recurrence, mortality, recovery similar; at 2 months 14/22 SEPS showed SDH resolution; 8/24 burr hole group showed resolution	
Sun et al. 2005	Prospective	112 pt; 4 expectant, 26 decadron, 13 burr hole, 69 burr hole plus decadron	1/26 decadron group required drainage; 3/69 (4%) decadron plus surgery recurred, re-operated; 2/13 (15%) surgery recurred,	1/26 death unrelated SAH; 2/69 death unrelated ICH, UTI; 2/13 death infection, cancer; 2/4 death liver failure, general

Table 2. (Continued)

Author	Type	Number of patients	Outcomes	Complications
Horn et al. 2006	Prospective based on preference	79 pt; 55/79 twist drill, 24/79 burr hole vs crani	re-operated; 2/4 expectant required surgery; 10/55 twist drill group required reoperation; 2/24 burr hole vs crani required reoperation; 4/55 death in twist drill group, 3/24 death in burr hole vs crani group	Twist drill: 3/55 aSDH, 2/55 required shunt, 1/55 seizure, 1/55 sepsis; Burr hole vs crani: 1/24 wound, 1 aSDH, 1 subdural shunt, 1 stroke, 2 worsening AMS
Ramchancran et al. 2007		165 burr hole with drain, 442 no drain	6/165 (4%) recurrence with drain, 130/442 (30%) recurrence no drain	
Gurelik et al. 2007	Prospective	42 pt burr hole irrigation, 38 with additional drain	Recurrence rates 4/38 (10.5%) with drain, 8/42 (19%) without; 17/224 (7.6%) recurrence with drain	
Gazzeri et al. 2007				
Kaplan et al. 2007	Prospective	10 pt burr hole, SDH > 2 cm	TCDs to assess MCA flow, all improved; 2/10 headache	None
Abouzari et al. 2007	Prospective RCT	84 pt unilateral tSDH, burr holes with closed drain, 42 flat for 3 days, 42 up	1/42 (2.3%) recurrence in flat group, 8/42 (19%) recurrence in HOB up group (1/42 required repeat burr hole)	Atelectasis 10 vs 7, pneumonia 5 vs 4, decubitus ulcer 3 vs 2, DVT 0 vs 1
Taussky et al. 2008	Retrospective	97 pt, 34/97 one burr hole; 63/97 two burr holes; closed system	10/34 one burr hole pt recurred ≥ 9 got subduroperitoneal shunts, 3/63 double burr hole did	3/34 had wound infection
Gokmen et al. 2008	RCT	70 pt, 32/70 burr hole, 38/70 twist drill	2/32 burr hole group recurred; 1/38 twist drill group recurred	2/70 deaths, 1/70 CN VI palsy
Khadka et al. 2008	Retrospective	365 pt, single burr hole evacuation, local anesthesia	17/365 recurrence, 360/365 ultimately done well	
Zakaraia et al. 2008	Cross-section	82 pt burr hole with drain; 42 pt no irrigation; 40Pt with irrigation	70/82 (85.4%) improved, 3 (3.7%) worse; no irrigation group: 35/42 (83.3%) better, 14.3% recurrence; irrigation group: 35/40 (87.5%) improved, 10% recurrence	40 vs 26.2% irrigation vs no irrigation group pneumocephalus
Guzel et al. 2008	Retrospective	20 pt with 24 SDH, MAC	20/20 improved, burr hole under MAC	None
Mobbs, Khong 2009	Prospective	10 pt burr hole, endoscope use	8/10 successful endoscope use, no recurrences	None
Shimamura et al. 2009	Prospective RCT	Burr hole, 24 h drain; 43 pt saline, 36 pt thrombin irrigation; AC reversed, anti-Plt continued, all got 24 h TXA	11/43 (25.6%) recurrence in saline irrigation group, 2/36 (5.5%) recurrence in thrombin group, all require surgical intervention (larger retrospective review of 331Pt SDH showed 10.1% recurrence)	None
Zumofen et al. 2009	Retrospective	147 pt, 183 cSDH, two burr holes, subperiosteal drain	24/183 (13.1%) recurrence; 15 (10.2%) required repeat burr hole, 2 (1.4%) craniotomy; 0.7% intra-op mortality (cardiac arrest)	3.4% death, 6.6% seizure, 1.6% infection (10.9% complication rate)
Santarius et al. 2009	Prospective RCT	215 pt, 108 with drain, 107 no drain; two burr holes	10/108 (9.3%) recurrence with drain, 26/107 (24%) w/o drain; trial stopped early due to benefit	9/105 (8.6%) vs 19/105 (18.1%) mortality in drain vs no drain group
Yu et al. 2009			8/121 (6.6%) recurrence with drain, 7/43 (16.3%) with < 3 days drain, 1/78 (1.3%) > 3 days	
Rughani et al. 2010	Case control, SEPS	129 pt, 28 SEPS, 57 burr hole, 44 craniotomy	7/28 SEPS pt vs 8/57 burr hole pt required additional procedures; 2/28 SEPS pt vs 3/57 burr hole pt died	

Table 2.   (Continued)

Author	Type	Number of patients	Outcomes	Complications
Miranda et al. 2011	Retrospective review	209 pt, 44 twist drill, 21 burr holes, 72 cranies	4/44 twist drill recurred, 1/21 burr hole recurred; 35/209 died in the hospital	14/178 twist drill complications (all recurrences), 56/270 burr hole complications (4 infection, 6 tension pneumocephalus, 5 parenchymal injury, 9 seizure, 32 recurrence)
Lin et al. 2011	Retrospective	448 pt, 178 twist drill, 270 burr hole with irrigation	Twist drill: 158/178 cured, 14/178 recurred ≥ repeat evacuation; burr hole: 204/270 cured, 32/270 recurred ≥ repeat OR	
Park et al. 2011	Prospective	31 pt, burr hole with irrigation, drain placement	31/31 resolved; 1/31 (3.2%) recurrence	
Ishibashi et al. 2011	Retrospective	58 pt burr hole, 34 pt burr hole with irrigation	48/58, 34/34 improved; 6/58 (10.3%) no irrigation recurred; 1/34 (2.9%) irrigation group recurred	2/58 (3.4%) died in no irrigation group due to MI, PNA
Javadi et al. 2011	Prospective RCT	40 pt two holes irrigation; 20 pt with drain, 20 pt no drain	At 1mth, 1/20 recurrence in drain group; at 6 months 1/20 recurrence in no drain group; both on anti-Plt	2/20 death in no drain group, 4/20 in drain group
Yeon et al. 2012	Single arm single center	20Pt saSDH or cSDH; warfarin pre-op	20/20 restarted warfarin d3 post op; 3/20 (15.8%) recurred at 1 month, requiring repeat burr hole	No VTE
Krieg et al. 2012	Consecutive series	320 cases, hollow screw placement under local, burr hole under general	63.3% treated with hollow screw, additional 16.2% with hollow screw × 2, 20.5% required burr hole w/ membranectomy; 80.3% improved post 1st surgery	1/320 EDH, 5/320 (1.6%) post-op meningitis; 16.6% UTI, 8.1% seizures, 4.7% PNA, 1.6% stroke, 0.9% PE, 0.6% DVT
Adeolu et al. 2012	Prospective	50 pt burr hole mobilized 25/50 d2 or 25/50 d7	Equally beneficial; 1/25 tension pneumocephalus requiring burr hole in d2	1/25 wound infection in d7
Kaliaperumal et al. 2012	Prospective RCT	50 pt two burr holes, drain × 48 h subperiosteal vs subdural	25 pt subperiosteal, 25 pt subdural drain; no difference in recurrence	1/25 subdural drain placed into parenchyma; 1/25 subperiosteal drain seizure
Neils et al. 2012	Retrospective	139 pt; 85 twist drill, 12 twist drill + tPA; 54 burr hole, 3 burr hole + tPA	30% recurrence twist drill ≥ 0% with tPA; 11.8% recurrence with burr hole ≥ 0% with tPA	None
Bellut et al. 2012			1.8% subperiosteal drain, 3.1% subdural drain	
Kim et al. 2014	Retrospective	65 pt, 48 twist drill, 17 burr hole drainage	42/48 (87.5%) twist drill and 13/17 (76.4%) burr hole improved; 4/48 (8.33%) twist drill recurred, 5/17 (29.4%) burr hole recurred	1/48 (2.4%) catheter failure
Singh et al. 2014	Prospective RCT	200 pt burr hole evacuation, 100 pt no drain, 100 pt drain	9/100 recurrence in the drain group; 26/100 recurrence in no drain group	5/100 death in drain group, 4/100 death in no drain group
Nayil et al. 2014	Prospective RCT	254 pt; 130 pt one vs 124 pt two burr holes, drain, flat × 48 h	6.15% recurrence with single burr hole; 4.83% with double burr holes	2/254 death
Kutty, Johny 2014	RCT	70 pt two burr holes; 70 pt burr hole plus drain	11/70 two burr hole group recurred w/reoperation, 1/70 burr hole plus drain	2/140 seizures; 1/140 death
Schwarz et al. 2015	Retrospective	193 pt with 250 cSDH, burr holes	Reoperation needed in 56/193 pt (29%) with 70 SDH	19/193 (9.8%) reoperation × 2, 5/193 (2.6%) × 3, 1/193 (0.5%) × 4
Wang et al. 2016	Observational retrospective	121 pt; 68 twist drill with YL-1 needle; 53 burr hole with irrigation	68/68 twist drill, 50/53 neurologically improved; 9/68 (13.2%) twist drill recurred ≥ 4 (5.9%) redo, 9/53 (17%) burr hole recurred ≥ 4 (7.5%) redo	Twist drill: 1/68 contusion, 9/68 pneumocephalus; burr hole: 3/53 acute SDH or EDH; 3/53 pneumonia, 46/53 pneumocephalus
Tanweer et al. 2016	Retrospective	14 pt, 20 SDH; SEPS plus oral TXA	SEPS: 145 + 40 cm³ ≥ 80 + 32 cm³ volume, 9.44 + 4.84 mm ≥ 4.44 + 3.29 mm of midline shift; post-TXA 7.41 + 15.54 cm³ volume,	1/14 emergent craniotomy for SEPS complication

Guzel et al. described successful BHE via single burr hole under MAC with no complications, beneficial for patients who cannot tolerate intubation or general anesthesia [29].

Single vs multiple BHE

Studies from 1970s describe chronic SDH patients treated with multiple BHE with 41% improvement, 25% deterioration, and 22.7% death [4]. Taussky et al. compared single vs multiple BHE in chronic SDH patients, reporting 29.4 vs 4.8% recurrence, respectively [30]. Zumofen et al. reported 86.9% success with 13.1% recurrence with BHE and overlying subgaleal drain; patients received antibiotics and phenytoin intra-operatively after reversal of asa/AC and remained flat for 48 h with drains below the head [31]. This study reported 6.6% seizures and 1.6% infections [31]. An RCT by Nayil et al. compared one vs two burr holes and reported 4–6% recurrences; patients remained flat for 48 hours [32]. Prospective study of BHE with irrigation and drain placement reported 100% SDH resolution with 3.2% recurrence [33].

Continued drainage

Drain placement is key, associated with lower recurrence of 3.1–10.5% with BHE and drain placement vs 17–33% without [34–37]. An RCT by Santarius et al. reported less recurrence with subdural drain placement (24 vs 9.3%); the trial was stopped early due to clear difference [38]. While Javadi et al. showed similar recurrence [39], Ramcharan et al. reported 4% recurrence with drain placement and 30% without [40]. An RCT by Singh et al. reported less recurrence with drain placement (26 vs 9%), with similar complications and mortality [41•]. An RCT by Kutty and Johny reported lower recurrence with single BHE with drain placement vs two BHE (1.4 vs 15.7%) [42]. Guilfoyle et al. published long-term follow-up from the Cambridge Chronic SDH Trial (CCSHT), indicating improved evacuation, less recurrence, and survival benefit 5 years postoperatively [43]. The timing of drainage may matter; Yu et al. reported 6.6% recurrence with drain placement, ranging from 16.3% with drain removal prior to 3 days to 1.3% if removed thereafter [44]. Drain location may likewise matter; subperiosteal drainage reduced seizure and infection risks avoiding SDH capsule, but was associated with higher recurrence [31]. Bellut et al. reported

Table 2. (Continued)

Author	Type	Number of patients	Outcomes	Complications
Yadav et al. 2016	Prospective; drain in subgaleal space overlying burr hole	260 pt; 140 burr hole, drain × 3 days; 120 no drain (60 × 1 burr hole, 60 × 2 burr hole); HOB up, irrigation	0.19 + 0.69 mm of midline shift at last follow-up; 10/14 complete resolution of symptoms, 3/14 improved; 134/140 drain improved, 114 no drain improved; 5/140 (3.57%) recurred in drain group, 12/120 (10%) recurred in no drain group	Drain: 2/140 deaths, 8/140 pneumocephalus; No drain: 2/120 deaths, 19/120 pneumocephalus
Unterhofer et al. 2016	Prospective RCT	52 pt, 57 SDH; burr hole w/ membrane opening vs not	Recurrent or clinically worse: 6/29 (21%) in burr hole w/ membrane opening 8/28 (28%) w/o membrane opening	2/29 aSDH, 1/28 aSDH in each group; no deaths
Brennan et al. 2017	Prospective observational multicenter cohort study	1205 pt; 700/787 burr holes × 2 (10% × 1); 72/787 craniotomy; 14/787 craniectomy; 16 steroids	73/787 (9%) recurrence, no difference burr hole 1 vs 2 vs crani; less with drain	60 PNA, 39 neuro deficit, 19 seizure, 12 arrhythmia, 9 stroke, 8 SSTI, 4 MI, 4 VTE; 18/798 (2%) death
Wang et al. 2017	Prospective	38 twist drill, 45 burr hole	7/38 (18.4%) twist drill recurred, 5/45 (11.1%) burr hole recurred	Twist drill: 1/38 wound infection, 1/38 pneumonia; burr hole 1/45 intracranial infection, 1/45 seizures, 1/45 pneumonia
Guilfoyle et al. 2017	Long-term RCT f/u	108 pt w/ drain, 107 pt w/o drain	At 5 years f/u 34.2% drain group, 47.7% control group died; no difference at 8-year and 10-year mark	

1.8% recurrence with subperiosteal drain and 3.1% with subdural drains [45]. Subgaleal drains with tip [37] or holes overlying burr hole [46] reduced recurrence as compared to no drain, avoiding injury to SDH membranes/parenchyma and pneumocephalus [46]. An RCT by Kaliaperumal et al. compared subdural vs subperiosteal drain placement with no recurrences with either, but better functional recovery with subperiosteal drains [47•].

Open vs closed system

Weir compared BHE with closed drainage vs catheter placement with passive drainage, former being superior [48]. An RCT by Laumer et al. compared closed drainage BHE vs implantation of silicone catheter with Rickham reservoir within burr hole, reporting similar recurrence; patients with Rickham required fourfold less repeat surgical interventions due to bedside access to reservoir [49]. Kwon et al. reported >200-cm^3 drainage with closed system BHE associated with 0% recurrence, <200-cm^3 drainage with open system BHE with 4.1% recurrence [50]. Kuroki et al. compared BHE with rapid drain placement vs BHE with irrigation and drain placement and found 1.8 vs 11.1% recurrence, respectively [51]. Kwon et al. further supported the reverse correlation between the amount of drainage and recurrence: re-accumulation was common with mixed density SDH and drainage volume < 200 cm^3 [50].

Active vs passive irrigation

Post-operative pneumocephalus is reduced by irrigation, supine positioning while filling SDH cavity, drain placement, and avoidance of intraoperative nitrous oxide [52]. Kitakami et al. reported BHE with saline irrigation followed by CO_2 resulting in rapid SDH cavity disappearance [53]. Hennig and Kloster reported lower (2.6%) recurrence with irrigation; BHE without irrigation showed high recurrence (32.6 vs 23.8%) with or without drain; 44.4% patients with recurrence required craniotomies [54]. Ishibashi et al. also reported 2.9% recurrence post-BHE with irrigation, as compared to 10.3% without irrigation [55]. A study of BHE by Zakaraia et al. with closed drainage with or without irrigation showed comparable recurrence [56].

Mobilization

Abouzari et al. evaluated BHE with irrigation and closed drainage; patients were randomized to remain flat for 3 days vs mobilized to 30–40° [57]. Patients remaining flat had 2.3% SDH recurrence, while those mobilized had 19% recurrence; pulmonary/thrombotic complications were similar [57]. Adeolu et al. compared mobilization day 2 vs 7, reporting no recurrence in either group [58]. Tsutsumi et al. reported higher recurrence with T1 hypointense SDH (11.6 vs 3.4%) [35]. Kaplan et al. used transcranial Dopplers to assess ipsilateral middle cerebral artery (MCA) flow upon evacuation of >2 cm SDH; MCA flow normalized with improvement in mental status and contralateral weakness [59].

Schwarz et al. reported midline shift, hypertension, bilateral SDH, and vitamin K antagonists as recurrence predictors [60]. Nakaguchi et al. reported 12% recurrence with <10-mm SDH vs 45% with >10-mm SDH, 26% recurrence with pneumocephalus vs 8% without, and 48% recurrence if >30% SDH cavity was air by volume [61]. Patients with frontal drains had 5% recurrence vs 38% with parietal, 36% with occipital, and 33% with temporal drains; patients with frontal drains had the least subdural air [61]. Unterhofer et al. reported comparable recurrence with or without membranectomy (21 vs 28%) [62•]. Mobbs and Khong suggested endoscopic visualization and subdural catheter placement, with a sharp division or electrocautery of membranes [63].

Adjunct therapies

Platelet-activating factor (PAF) levels are increased within acute SDH, localizing to perisinusoidal vessels in SDH membranes [64]. Hirashima et al. reported 0% recurrence with 1.5–3mg daily etizolam (PAF-dependent platelet aggregation inhibitor) vs 29.2% in controls [65]. Sun et al. reported less recurrence with dexamethasone [66]. Neils et al. evaluated intra-cavity tPA, reporting 30% recurrence with TDC, 11.8% with BHE, and 0% with BHE and tPA; the mean evacuated volume increased from 26 to 100 cm^3 [24]. Shimamura et al. RCT reported a fivefold reduction in recurrence (25.6 vs 5.5%) with BHE, drain, and SDH cavity irrigation with 100 u/ml thrombin regardless of systemic anti-

platelets; TXA was administered for 24 h [67]. Thrombin may aid hemostasis by inducing vessel constriction and fibrin deposition by binding its receptor on sinusoidal endothelium that undergoes microhemorrhaging in SDH hyperfibrinolytic state [68]. Yeon et al. reported no change in SDH recurrence if warfarin was restarted 3 days post-operatively [69].

Twist drill vs burr hole evacuation

Smely et al. reported 18.2% recurrence and 6% death with TDC and 33% recurrence and 10% death with BHE [70]. Williams et al. reported 63.6% deterioration with TDC, compared to 16% deterioration with BHE and 7% with BHE and drain placement [71]. An RCT by Muzii et al. compared SEPS vs BHE with irrigation and drain placement; recurrence, mortality, and recovery were similar (18.2 vs 33.3%) [72]. Gokmen et al. reported similar SDH recurrences, 2.6% in TDC and 6.3% in BHE group [73]. Lin reported improved cure rate with TDC vs BHE (88.8 vs 75.5%) with less recurrence requiring repeat interventions (7.9 vs 11.9%) and less complications (7.9 vs 20.7%) [74]. Kim et al. reported similar outcomes [75]. Wang et al. treated patients with twist drill YL-1 needle vs BHE with irrigation, reporting 100 vs 94.3% improvement and 13.2 vs 17% recurrence; another prospective study reported 18.4 vs 11.1% recurrence with TDC vs BHE [23, 76]. Finally, Brennan et al. reported 2% mortality, 14% morbidity, 9% recurrences, and 22% unfavorable outcomes associated with BHE, with patient age, bed rest, and single burr hole being independent predictors of poor functional outcome, and failure to insert the drain as a predictor of recurrence and unfavorable functional outcome [77].

Craniotomy for acute SDH

Craniotomy is useful for treating acute SDH with thick clot and chronic or subacute SDH that failed other treatments with significant radiographic progression, or SDH with septations (Table 3). Management of acute SDH depends on patient prognosis, goals of care, and hospital course; it is life-threatening due to the underlying structural TBI associated with up to 92% mortality. Surgical evacuation via open craniotomy is indicated for acute SDH with >1-cm thickness or >5-mm midline shift [78], deteriorating patient with the Glasgow Coma Scale (GCS) <8, unilateral or bilateral fixed dilated pupils, or evidence of elevated increased intracranial pressure (ICP) >20 [79]. Modifications include craniotomy or craniectomy, with or without partial or complete resection of SDH membranes. SDH etiology, patient age, time to surgical treatment, pre- and post-operative ICPs, and extent of craniotomy or decompressive craniectomy affect outcomes. Subdural hygromas require surgical interventions if behaving aggressively, including evacuation, placement of ventriculoperitoneal or subduroperitoneal shunt, or cranioplasty.

Morbidity and mortality in acute SDH patients remain high due to underlying parenchymal injury, loss of autoregulation, poor preoperative neurologic state, and uncontrolled post-operative ICPs. Britt and Hamilton proposed large decompressive craniectomy for acute SDH in 1978 [80]. Koc et al. reported 38% functional recovery in 91% acute SDH patients with GCS 9–15, with a mortality over 90% in patients with GCS 3–4, bilaterally nonreactive pupils, or intracerebral hematomas; 80% mortality was reported in patients with unilaterally nonreactive pupil or subarachnoid hemorrhage [81]. Guilburd and Sviri described acute SDH evacuation through multiple dural fenestrations with > 80% success; however, 51.6% expired and over third sustained persistently elevated ICPs >25 refractory to medical management [82]. An RCT by Jiang et al. investigated large frontotemporoparietal decompression vs temporoparietal decompression in patients with severe TBI and refractory ICPs [83]. More patients with wide decompression showed improvement (39.8 vs 28.6%) with better survival and less neurodeficits [83]. Smaller studies showed no difference in outcomes [84].

A study of severe TBI patients by Ucar et al., conducted to identify GCS cutoff for patients that benefit from decompression and address its timing, indicated that decompression should occur ≤4 h from injury and is futile with GCS ≤5 [85]. Woertgen et al. reported no difference in outcomes in acute SDH patients undergoing craniotomy or decompressive hemicraniectomy; however, mortality due to herniation was higher with decompression (53 vs 32.3%) [86]. Missori et al. used double dural sheets with decompression to aid with temporalis dissection during cranioplasty [87]. Nguyen et al. performed fenestration on bone prior to replacement, with improved post-operative SDH volumes, better drainage, and reduced recurrences

Table 3. Craniotomy studies

Author	Type	Number of patients	Outcomes	Complications
Tabaddor and Shulmon 1977	Observational, craniotomy	28 pt, chronic subacute SDH	Closed system: groups 1–4: intact, lethargic, stuporous or comatose; 3/28 unchanged, 11/28 improved, 6/22 deteriorated, 8/22 deaths	6 deteriorated, 8 deaths
Hamilton et al. 1993	Retrospective, cSDH	92 pt, 43 pt burr hole, 49Pt crani	71.7% improved; 3/41 (7.3%) recurrence burr hole, 5/47 (10.6%) recurrence crani	6/41 (14.6%) burr hole, 7/47 (14.9%) crani
Koc et al. 1997	Retrospective	113 pt, tSDH, craniotomy	38% improved (91% GCS 9–15, 23% GCS 3–8); 97% b/l NR pupils, 81% unilateral NR pupil died	60% mortality (GCS 3 ≥100% died; GCS 4–5 75–95% died)
Ernestus et al. 1997	Retrospective, cSDH	104 pt, 94 pt burr hole, 10 pt crani	71.7 vs 62.5% improved; 17/92 (18.5%) burr hole recurred, 1/8 (12.5%) crani recurred	Mortality 2/94 (2.1%) burr hole, 2/10 (20%) crani
Beatty et al. 1999	Retrospective, c/SDH	23 pt, all minicrani	21/23 (91%) improved, 0% recurred	2/23 (8.7%) mortality
Tanikawa et al. 2001	Retrospective, cSDH	49 pt, 33 burr hole, 16 crani	4/32 (12.5%) recurrence burr hole, 0% recurrence crani	Mortality 1/33 (3%) burr hole, 0% crani
Guilburd, Sviri 2001	Prospective	31 pt aSDH, multiple dural fenestrations	29/31 > 80% evacuation; 12/31 w/ post-op ICPs>25; 16/31 (51.6%) overall mortality	1 meningitis; 21 PNA, 13 sepsis, 2 DVT, 1 PE
Mohamed 2003	Retrospective	39Pt, crani w/ outer membranectomy	0% recurrences; 5% required once percutaneous tapping and aspiration	0% mortality
Lee et al. 2004	Retrospective, cSDH	172 pt, 38 burr hole, 121 minicrani partial membranectomy, 13 crani full membranectomy	69% improved; recurrence 6/38 (15.8%) burr hole, 22/121 (18.2%) minicrani, 3/13 (23%) crani group	8/172 (4.7%) mortality; 0% complications in burr hole or crani group; 2/121 (1.7%) in minicrani group
Jiang et al. 2005	Multicenter RCT	486 pt, refractory ICPs, number of aSDH vs IPH unclear	241 FTP bone 12 × 15-cm flap; 245 TP 6 × 8-cm bone flap; 96/241 (39.8%) FTP improved; 70/245 (28.6%) improved	FTP: 73 severe deficits, 9 vegetative, 63 died; TP: 82 severe deficits, 7 vegetative, 86 died
Ucar et al. 2005	Decompressive craniectomy, unilateral 66, bilateral 34	100 pt, 40/100 mass lesions (32 unilateral, 8 bilateral decompression) 32 aSDH	84/100 unfavorable outcomes, 16/100 favorable; GCS 4–5: 2/60 (3.4%) favorable, GCS 6–8: 14/40 (25%) favorable; 2/32 aSDH with favorable outcomes	8/66 (12.2%) unilateral decompressions effusion or contralateral SDH, 5/8 OR; 13 SSTI
Woertgen et al. 2006	Retrospective	180 pt traumatic aSDH, 111 craniotomy, 69 decompressive craniectomy	Craniotomy: 63% residual, 1% massive bleed, 1.8% EDH, 53% ICP > 20 Craniectomy: 40% residual, 4.3% massive bleed, 1.4% EDH, 73% ICP > 20	32.3% mortality craniotomy, 53% decompressive craniectomy
Horn et al. 2006	Prospective	79 pt, 91 cSDH; 55 twist drill, 24 burr hole vs crani	Burr hole vs crani 74% improved, 8% recurred; twist drill 84% improve, 18% recurred	18% twist drill including 6% aSDH, 4% shunt, 4% resp. failure; 25% burr hole vs crani including 8% decline, 4% shunt, 4% aSDH, 4% stroke, 4% wound revision
Rocchi et al. 2007	Retrospective	14 pt crani with membranectomy	0% recurrences	3/14 (21.4%) complications
Missori et al. 2008	Case series	11 pt decompressive craniectomy, double dural patch	11/11 clear cleavage plane identified between internal and external dural patch	None
Lee et al. 2009	Retrospective	87 pt, 25 burr hole, 32 multiple, 30 minicrani	Recurrence 24% burr hole, 22% multiple burr holes, 6.7% minicrani	Complications 16, 16, and 3%
Lindvall and Koskinen 2009	Retrospectives	71 pt, cSDH; 54Pt trauma; 59 pt burr hole, 7 pt crani	17% recurred in all patients; AC more used in nontraumatic group	1 death
Mondorf et al. 2009	Retrospective	193 pt, 151 crani, 42 burr hole	41% improved; 27.8% crani recurred, 14.3% burr hole recurred	5% death
White et al. 2010	Retrospective	246 pt, 130 burr hole, 116 minicrani	Burr hole: 64/77 (83.1%) improved, 23/130 (17.7% recurrence; minicrani: 66/90 (73.3%) improved, 23/116 (19.8%) recurrence)	Mortality 10/130 (7.7%) burr hole, 20/116 (17.2%) minicrani; complications 14/130 (10.8%) burr hole, 13/116 (11.2%) crani

Table 3. (Continued)

Author	Type	Number of patients	Outcomes	Complications
Kim et al. 2011	Retrospective	317 pt, 259 burr hole, 16 minicrani partial membranectomy, 42 crani full membranectomy	Improved: 88% burr hole, minicrani; 90% crani; recurrence 23/259 (8.9%) burr hole, 8/16 (50%) minicrani, 4/42 (9.5%) crani	Mortality: 21/259 (8.1%) burr hole, 0% minicrani; 2/42 (9.5%) crani; complications 9/259 (3.5%) burr hole, 1/16 (6.2%) minicrani, 2/42 (4.8%) crani
Schulz, Mauer 2011	Prospective non randomized	50 pt > 65 years acute tSDH; 25 pt limited craniotomy, 25 pt decompressive	SDH volume, midline shift time to OR same; outcomes the same	
Godlewski et al. 2013	Retrospective	100 pt total, 42 pt cSDH, 35 burr hole, 7 crani	13/35 (37.1%) recurrence burr hole, 3/7 (42.9%) crani	1/34 (2.9%) death; 2/34 (5.9%) complication
Callovini et al. 2014	Retrospective	34 crani membranectomy	Improved: 89%; 2/34 (5.9%) recurrence	
Van der veken et al. 2014	Retrospective, cSDH	126 pt, 3–4 cm minicrani	106/126 (84%) improved, 11/126 (8.7%) recurred	17/126 (13.5%) mortality; 8/43 (6.3%) complications
Regan et al. 2015	Retrospective, cSDH	119 pt, 61 burr hole, 58 5–7 cm mini crani	4/61 (6.6%) burr hole recurrence, 14/58 (24.1%) minicrani	Mortality 2/61 (3.3%) burr hole, 6/58 (6.9%) minicrani; complications 8/61 (13.1%) burr hole, 26/58 (44.8%) minicrani
Unterhofer et al. 2016	RCT, cSDH	57 pt, 28 pt 3 cm minicrani, 28 pt minicrani membranectomy	Recurrence rate 6/28 (21.4%) minicrani, 8/28 (28.6%) minicrani with membranectomy	Mortality 0% in either group
Nguyen et al. 2016	Prospective	44 pt; 33/44 bone fenestrated, 11/44 not	3/11 non-fenestrated recurred; 1/33 fenestrated recurred	None
Zhang et al. 2017	Retrospective	43 pt Endoscope burr hole, 27 pt craniotomy	OR time 95.3 vs 56.5 min; EBL 213.2 vs 34.5 cm³, zero recurrences in each; 4/27 death in crani	Morbidity: 2/43 (4.7%) endoscopic; vs 17/27 (63%) crani; pneumocephalus 2 vs 6; seizures 1 vs 4, PNA 0 vs 4, ICH 0 vs 1, wound infection 0 vs 2, PONV 0 vs 7
Balevi 2017	Retrospective	28 pt cSDH, large crani with membranectomy	11.9% recurrence × 24 h	22.8% tension PTX; 25% seizure; 4/28 (14.28%) died
Mahmoud et al. 2017	Retrospective	35 pt mini crani, 16 under local, 19 under general	0 recurrence in local group, 2.86% in general	4/16 local, 7/19 general

[88]. Other studies described floating or hinge craniotomies (bone attached to cranium with sutures [89], Y-shaped titanium plates [90], or temporalis muscle [90, 91]), or using divided bone flaps with multiple hinges [92].

Craniotomy for chronic SDH

Chronic SDH evacuation via craniotomy is associated with better outcomes. Tabaddor and Shulmon reported 39.3% clinical improvement, 21.4% deterioration, and 28.6% mortality; a later study by Hamilton et al. reported 71.7% improvement, 10.6% recurrence, and 14.9% complications [4, 93]. Ernestus et al., Callovini et al., and Van der Veken reported similar numbers [94–96]. Godlewski et al. compared patients with acute, subacute, and chronic SDH; 83.5% chronic, 75% subacute, and 10.5% acute SDH patients underwent BHE, with 37.1, 26.7, and 25% recurrences, respectively; the remaining patients were treated with craniotomy/craniectomy [97]. In craniotomy/craniectomy group, 5.9% of acute SDH, 60% of subacute, and 42.9% of chronic SDH patients had recurrences [97]. Craniotomy/craniectomy patients with acute SDH did well, while subacute/chronic SDH patients best responded to BHE.

Extensive craniectomy may not be important in treating chronic SDH patients. Beatty et al. reported 91% improvement with 8.7% mortality post-minicraniectomy [98]. A study by Lee et al. comparing BHE vs 3-cm craniotomy with membranectomy vs extended craniotomy with membranectomy reported 16, 18 and 23% recurrences, respectively [99]. Lindval and Koskinen likewise reported 17% recurrences irrespective of anti-platelet use [100]. Mahmoud et al. reported 2.86% recurrence with minicraniectomies [101]. Horn et al. reported 8% recurrence in BHE vs craniotomy groups [102], while White et al. reported 17.7 vs 19.8% recurrence, with 2.5-fold higher (17.2%) mortality in the latter [103]. Regan et al. showed 6.6% recurrence and 3.3% mortality in patients undergoing BHE; recurrence post-minicraniotomy was 24.1% with mortality of 6.9% [104•]. Mondorf et al. reported 27.8 vs 14.3% recurrence with craniotomy vs BHE [105]. Kim et al. reported ~90% improvement regardless of technique; patients undergoing BHE had 8.9% recurrences with 8.1% mortality, vs 50% recurrence post minicraniotomy, and 9.5% recurrence with 9.5% mortality after extensive craniotomy [106].

Membranectomy may be beneficial. Tanikawa et al. reported 0% recurrence with patients undergoing craniotomy, including chronic SDH patients with multiple membranes [107]. Mohamed et al. reported no recurrence with craniotomy, durectomy, outer membranectomy, and drain placement, with two patients requiring percutaneous tapping [108]. Rocchi et al. reported zero recurrence with membranectomy, with 21.4% complications including seizures and a hemorrhagic infarct [109]. Balevi et al. reported 11.9% recurrence following large craniectomy with membranectomy within 24 h; 22.8% patients developed tension pneumothorax, 25% had seizures, and 14.28% expired [110]. An RCT by Unterhofer et al. reported a comparable 21.4% recurrence with minicraniotomy vs 28.6% with additional membranectomy, possibly due to inability of atrophied brain to re-expand and formation of neomembranes [62•].

Bilateral chronic SDH

Bilateral chronic SDHs have an incidence of 15–25% and are associated with higher recurrence and worse outcomes, with advanced age, diabetes, coagulation abnormalities, altered mental status, gait instability, and less midline shift associated with bilateral SDH [111–114]. Hsieh et al. reported age as a risk factor, with similar complication and recurrence in patients with unilateral vs bilateral BHE [115]. Lee and Park reported similar recurrence post-BHE with bilateral vs unilateral SDH (21.4 vs 16.3%), with favorable outcome and improvement less likely with bilateral SDH [113]. Fujitani et al. reported that SDH's iso- or hypointensity on MRI were a single predictor of contralateral SDH enlargement in patients with bilateral chronic SDH undergoing unilateral BHE [116].

Few reports describe SAH, IPH, and acute SDH after bilateral BHE; neurologic deterioration may also occur after bilateral craniotomies due to brain sag [117, 118]. Decision-making is complicated if significant differences in SDH size/thickness or lateralization of symptoms are present, suggesting that one SDH is asymptomatic. Lee et al. described TDC for bilateral SDH, 20% patients requiring reoperation [119]. Recent review reported 21.6% recurrences in 136 unilaterally treated patients with bilateral SDH, 28.7% requiring repeat treatment; the absence of post-operative drainage and mixed density SDH were independent predictors for retreatment [120]. A

review of 500 chronic SDH patients by Mori et al. showed 49 recurrences, 18 being contralateral to the operated side, and 14 of these having a contralateral thin SDH/effusion on preoperative CT [121]. SDH recurrences may result from ICP alterations and decreased tamponade effect due to brain displacement toward the surgical side, allowing re-expansion of contralateral SDH [121].

Conclusions

Optimizing surgical management for various types of subdural hemorrhages is needed. Recurrence rates are highest with twist drill craniostomies, although they have significant advantages of procedure completion at bedside or under MAC. Closed system, active irrigation, continued drainage, and mobilization have been associated with better outcomes with twist drill and burr hole SDH evacuation. Craniotomy carries the highest morbidity and mortality, especially in older patients who are more likely to be on anti-platelets or anticoagulation, but should be the method of choice in treating recurrent chronic SDH with multiple membranes, or acute SDH in deteriorating patients. Management of bilateral chronic SDH remains under investigation. Patients with SDH are served best by a specialized multidisciplinary team, individualized approach, and rapid surgical interventions, if needed.

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Compliance with Ethical Standards

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Human and Animal Rights and Informed Consent
This article does not contain any studies with human or animal subjects performed by any of the authors

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