Benefits of the Subdural Evacuating Port System (SEPS) Procedure Over Traditional Craniotomy for Subdural Hematoma Evacuation

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Abstract

Background: There remains no consensus on the optimal primary intervention for subdural hematoma (SDH). Although historically favored, craniotomy carries substantial morbidity and incurs significant costs. Contrastingly, the subdural evacuating port system (SEPS) is a minimally invasive bedside procedure. We assessed the benefits of SEPS over traditional craniotomy for SDH evacuation. **Methods:** A single-center retrospective cohort study of SDH patients receiving craniotomy or SEPS between 2012 and 2017 was performed. Information regarding demographics, medical history, presentation, surgical outcomes, cost, and complications was collected. Pre- and postoperative hematoma volumes were calculated using 3D image segmentation using Vitrea software. Multivariate regression models were employed to assess the influence of intervention choice. **Results:** Of 107 patients, 68 underwent craniotomy and 39 underwent SEPS. There were no differences in age, sex, blood thinner use, platelet count, INR, hematoma lateralization, age, volume, or midline shift at presentation between intervention groups. Although there was no difference in percent residual hematoma volume 24-hour postintervention (44.1% vs 45.1%, $P = .894$), SEPS was associated with lower hospitalization costs (\$108 391 vs \$166 318, $*P = .002$), shorter length of stay (4.0 vs 5.8 days, $*P = .0002$), and fewer postoperative seizures (2.6% vs 17.7%, $*P = .048$). Reoperation rate was higher after SEPS overall (33.3% vs 13.2%, $*P = .048$) but comparable to craniotomy in chronic SDH (12.50% vs 7.69%, $P = 1.000$). **Conclusion:** In this retrospective cohort, SEPS was noninferior to craniotomy at reducing SDH hematoma volume. The SEPS procedure was also associated with decreased length of stay hospitalization costs, and postoperative seizures and demonstrated a comparable recurrence rate to craniotomy for chronic SDH in particular.

Keywords

craniotomy, SEPS, subdural hematoma, twist-drill craniostomy

Introduction

Subdural hematoma (SDH) is a common presentation in neurosurgery and neurocritical care, particularly in elderly populations. The incidence of SDH ranges from 3 to 58 per 100,000 individuals annually, with greater incidence in persons older than 65.¹⁻³ Given the aging population and the advent of new oral anticoagulants, the incidence of SDH is expected to continue to increase over time.⁴ SDH can be classified both by age of blood (acute [aSDH] or chronic [cSDH]) and by etiology (traumatic, spontaneous, iatrogenic, etc). Subdural hematoma is thought to arise from the tearing of bridging veins either by acute trauma, as is the case in most aSDH cases, or by mechanical stress from the evolution of a subdural hygroma in the setting of cortical atrophy (in most cSDH cases).⁵ There are several options for treatment of SDH including

craniotomy, bedside burr hole drainage, medical management with steroid taper or tranexamic acid, and more recently some less invasive methods such as endovascular arterial

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embolization.⁵⁻⁷ Interestingly, despite the prevalence of SDH, there is little consensus on which of these methods should be considered first line, particularly in cases of cSDH, which has a more complex physiology.⁸

Because SDH is most common in older patients with high operative risk, there is growing interest in minimally invasive methods for SDH evacuation. The twist-drill craniostomy (TDC), first described in the 1960s, was introduced as a potential alternative to burr hole craniotomy (BHC) that could easily be performed at the bedside.⁹ The TDC technique evolved with the invention of the hollow “bolt,” which was developed 20 years ago to improve overall efficiency of drainage.¹⁰ To implement this minimally invasive approach using a hollow screw to promote gradual suction drainage under negative pressure, the subdural evacuating port system (SEPS; Medtronic, Inc., Dublin, Ireland) device was developed. The SEPS kit is comprehensive; it contains both the equipment needed for insertion and the components for drainage. Its key advantages include the creation of an airtight seal for drainage and avoidance of catheter placement in the subdural space.¹¹⁻¹³ Several series have demonstrated the positive safety profile of the bedside SEPS, especially after a period of prolonged institutional experience, but few discuss the comparative effectiveness of SEPS versus alternative intervention.¹³⁻¹⁵ Additionally, it has been suggested that the SEPS procedure is less likely to result in reoperation when treating collections that are hypodense on computed tomography (CT; cSDHs).¹⁶ As a consequence, the vast majority of existing observational data on the SEPS has been limited to the cSDH population.^{13,15,17}

In this study, we analyzed a single institution’s experience with SEPS compared to craniotomy across all SDH subtypes. In addition to examining clinical outcomes such as hematoma volume reduction and postoperative complications (including need for reoperation), cost-effectiveness factors such as cost of hospitalization and length of stay were also studied.

Methods

As part of a quality assurance (QA) project, a retrospective review of all adult SDH patients at a single academic medical center treated by either SEPS or craniotomy first line between 2012 and 2017 was conducted. A waiver of informed consent was granted by the institutional review board for this study given its retrospective nature and because it was part of a hospital system QA effort. The decision to perform a SEPS procedure was based on physician preference, and cases belonging to 15 different attending surgeons were reviewed. Patients with SDH of all densities on CT imaging were included in the study. Patients without follow-up imaging within (1) 24 hours postoperatively and (2) a minimum of 3 weeks from initial intervention were excluded.

Data on patient demographics, medical history, presenting symptoms, and imaging during the index admission were reviewed, and postoperative imaging, complications, and

outcomes data through each patient’s most recent follow-up were likewise collected from original images, radiology reports, and neurosurgery clinic notes. Imaging characteristics including hematoma age, hematoma lateralization, and midline shift were determined from available CT scans or magnetic resonance imaging images by a 2-person reviewing team for at least 3 clinical time points: (1) preoperatively, (2) within 24 hours postoperatively, and (3) at most recent follow-up (a minimum of 3 weeks since index admission). Additional imaging and data were likewise collected for admissions for reoperation or additional procedures for SDH. Hematoma age was assessed by subjective appearance of hematoma density relative to underlying brain parenchyma. Midline shift was measured by placing a midsagittal reference line at the level of the foramen of Monroe and measuring the perpendicular distance of the foramen to the midline. Pre- and postintervention hematoma volumes were measured using Vitrea (Vital Images, Inc., Minnetonka, MN) workstation 3D segmentation tools. For each image, hematoma volume was measured by manual segmentation and 3D reconstruction of evident SDH on each 4-mm slice—an average of 35 slices per image—and then compiled to produce a volumetric rendering. Pneumocephalus, existing drains, or other intracranial instrumentation or devices were not included in the segmentation volume. Recurrence was defined as development or worsening of symptoms attributable to enlargement of hematoma as seen on imaging and then requiring additional intervention at any time during follow-up. Additionally, cost of hospitalization and length of stay were extracted from review of billing information for the index SDH admission.

In this study, craniotomy procedures consisted of either bone-flap craniotomies or BHCs. In all cases, craniotomy was performed in the operating room under general anesthesia. After standard skin incision, and burr holes or bone flaps were made, the dura was opened in a stellate fashion with care to preserve all nearby bridging veins. Copious irrigation was used to evacuate subdural blood until irrigation was visibly clear. After placement of at least one subdural/subgaleal drain, the dura was loosely reapproximated. The SEPS procedures were similarly standardized and performed at the bedside under moderate sedation with additional local anesthesia. A linear skin incision was made and the periosteum scraped away, a twist-drill burr hole was created, the dura incised, and the SEPS device was secured. In some cases, bilateral craniotomies or bilateral SEPS were performed as clinically appropriate. In all cases, subdural drains or SEPS devices were left until 24-hour drainage of less than 20 to 30 cc of was observed. Additionally, after intervention, all patients were placed on 14 days of antiepileptic prophylaxis with levetiracetam.

All statistical analysis was performed using SAS, version 9.4 (SAS Institute Inc., Cary, NC). Univariate analyses for continuous variables were performed using the independent samples *t* test and Mann-Whitney *U* test as appropriate, and χ^2 and Fisher exact tests were employed for categorical

Table 1. Patient Characteristics by Intervention Arm.^a

Characteristic	Craniotomy (N = 68)	SEPS (N = 39)	P Value
Age—years (mean ± SE)	66.8 ± 2.2	68.7 ± 2.4	.587
Gender			.466
Male	46 (67.7)	29 (74.4)	
Female	22 (32.3)	10 (25.6)	
Home medications			
Anticoagulation	10 (14.7)	5 (12.8)	.787
Antiplatelet agent	23 (33.8)	13 (33.3)	.959
Statin	20 (29.4)	15 (38.5)	.337
Preoperative laboratory values			
Platelet count—10 ³ /μL (mean ± SE)	235.3 ± 11.3	234.6 ± 14.5	.972
INR (median, IQR)	1.0 [1.0-1.2]	1.0 [1.0-1.1]	.256
Presenting symptoms			
Headache	40 (58.8)	22 (56.4)	.808
Altered mental status	15 (22.1)	9 (23.1)	.903
Seizure	7 (10.3)	0 (0)	.046 ^b
Focal weakness	26 (38.2)	17 (43.6)	.587
Focal sensory deficit	2 (2.9)	0 (0)	.532
Aphasia	12 (16.9)	4 (9.8)	.247
Imaging characteristics			
Dominant hematoma lateralization			.928
Left	36 (52.9)	21 (53.9)	
Right	32 (47.1)	18 (46.1)	
Bilateral hematomas	14 (20.6)	13 (33.3)	.144
Hematoma age			.229
Acute	14 (20.6)	3 (7.7)	
Subacute	41 (60.3)	28 (71.8)	
Chronic	13 (19.1)	8 (20.5)	
Hematoma volume at presentation—mL (mean ± SE)	28.6 ± 2.0	32.7 ± 1.9	.162
Midline shift (MLS) at Presentation—mm (mean ± SE)	8.0 ± 0.6	7.7 ± 0.8	.761

Abbreviations: INR, international normalized ratio; IQR, interquartile range; SE, standard error; SEPS, subdural evacuating port system.

^aN (%) indicates percentage of cases in each group; Values are given as n (%), which indicates percentage of cases in each group, and interquartile range.

^bSignificantly different between 2 intervention arms for $\alpha = .05$.

univariate comparisons as appropriate. Two-way analysis of variance (ANOVA) was used for multiple comparisons of continuous variables. To adjust for potential effect-modifying variables on the impact of intervention (SEPS or craniotomy) on any outcome, multivariate linear and logistic regression analyses were performed for continuous and categorical outcomes, respectively. Prior to use in multivariate regression, log transformation of variables was performed for non-normal distributions and retested for normality using the Shapiro-Wilk test. In both linear and logistic regression models, variables with a significance of $P < .3$ were tested according to a stepwise method, and those variables with a significance of contribution of $P < .05$ were considered effect modifiers and were retained in the models.

Results

Patient Population

Retrospective chart review over a 5-year period (2012-2017) yielded 107 patients with SDH treated with either SEPS (n = 39) or craniotomy (n = 68) first line. In the craniotomy group,

49 (72%) patients underwent bone-flap craniotomy, and 19 (28%) patients underwent BHC with single or multiple burr holes, but all received subdural drains. There were no significant differences in age, sex, anticoagulant, antiplatelet or statin use, or preoperative INR or platelet count between patients who received SEPS versus craniotomy. Of the presenting neurological symptoms, incidence of seizure was slightly increased in the craniotomy group ($*P = .046$). On imaging, there were no differences in hematoma lateralization, bilaterality, or hematoma age (based on density on preoperative CT images) between the 2 intervention groups. Additionally, hematoma volume at presentation ($P = .172$) and midline shift at the time of intervention ($P = .761$) were also equitable (Table 1). The mean follow-up period in the craniotomy group was moderately longer than in the SEPS group (13.87 ± 2.16 months vs 6.69 ± 1.05 months, $*P = .02$).

Postoperative Hematoma Volumes

The primary outcome of the study examined immediate postoperative hematoma evacuation efficiency. On post-intervention CT images, percent residual blood volumes were

Table 2. Primary and Secondary Outcomes.^a

Outcome	Craniotomy Mean, SE	SEPS Mean, SE	Regression Coefficient (β) (>0 Positively Associated With SEPS)	95% CI	P Value
Primary outcome					
% Residual hematoma volume (after index intervention on 24-hour CT)	45.1 $\pm$ 5.3	44.1 $\pm$ 4.1	−0.01	[−0.16 to 0.14]	.894
Secondary outcomes					
Cost of hospitalization (\$)	166 318 $\pm$ 21 452	108 391 $\pm$ 11 124	−0.34	[−0.54 to −0.13]	.002 ^b
Length of hospital stay (days)	5.8 $\pm$ 0.4	4.0 $\pm$ 0.4	−0.38	[−0.57 to −0.13]	.0002 ^b

Abbreviations: CI, confidence interval; CT, computed tomography; SEPS, subdural evacuating port system.

^aAnalysis performed by multivariate linear regression for continuous variables; sign of β indicates association with SEPS. Effect modifiers with a *P* value of <.05 were included in the models for each outcome.

^bSignificantly different between 2 intervention arms for $\alpha = .05$.

equivalent between SEPS (mean 45.1% $\pm$ 5.3%) and craniotomy (mean 44.1% $\pm$ 4.1%) in both univariate and multivariate analysis (*P* = .894; Table 2, Figure 1A). No effect modifiers carrying a significant contribution of *P* < .05 requiring model adjustment were identified after multivariate linear regression (β = −0.01 for association with SEPS, 95% confidence interval, CI [−0.16 to 0.14], *P* = .894). Associated regression tables can be found in *supplementary materials*. In subgroup analysis by hematoma age, 2-way ANOVA estimating the impact of both hematoma age and the index intervention on hematoma volume reduction revealed a significant impact of the interaction of hematoma age and intervention (*F* = 4.62, **P* = .034). Although insufficiently powered to show significance, post-hoc analysis of this ANOVA shows a trend toward SEPS generating greater 24-hour hematoma volume reduction in chronic SDH (*P* = .195) versus acute or subacute SDH (*P* = .851; Table 3).

Cost-Effectiveness Outcomes

In an effort to perform cost-benefit analysis, hospitalization costs and length of stay with SEPS or craniotomy were reviewed as secondary outcomes. After adjusting for anticoagulant use, platelet count at presentation, and dominant hematoma lateralization (Table 4), having a SEPS significantly decreased overall cost of hospitalization (β = −0.34 for association with SEPS, 95% CI [−0.54 to −0.13], **P* = .002; Table 2, Figure 1A). Furthermore, when isolating and considering only those cases of SEPS that required reoperation during the same admission (*n* = 10 patients, *n* = 6 received craniotomy, and *n* = 4 received a second SEPS), cost of overall hospitalization was still comparable to that of craniotomy (*P* = .891). Distribution of hospitalization costs across intervention groups can be seen in Figure 2. Additionally, after adjusting for age, INR at presentation, and dominant hematoma lateralization (Table 5), SEPS was also associated with decreased length of stay compared to craniotomy (β = −0.36 for association with SEPS, 95% CI [−0.57 to −0.15], **P* = .009; Table 2, Figure 1A).

Recurrence Rates and Complications

Recurrence rates of symptomatic and radiographic SDH requiring reoperation were higher after SEPS (33.3%) than after craniotomy (13.1%). No effect modifiers were identified affecting this outcome in multivariate logistic regression (*see supplementary materials*). The odds of recurrence after SEPS was over 3 times more likely than after craniotomy (odds ratio [OR]: 3.28 for association with SEPS, 95% CI [1.25-8.62], **P* = .016; Table 6, Figure 1B). In subgroup analysis by hematoma age, recurrence in acute or subacute SDH was significantly greater after SEPS versus after craniotomy (*P* = .011), but recurrence rates were comparable in cSDH (*P* = 1.000; Table 6).

The incidence of postoperative seizure overall was significantly lower after SEPS (2.6%) versus craniotomy (17.7%), independent of preoperative presentation of seizure. Preoperative seizure status did not achieve significance to modify postoperative seizure outcomes in multivariate analysis (*see supplementary materials*). Overall, our cohort was 88% less likely to experience postoperative seizure after SEPS than after craniotomy (OR: 0.12 for association with SEPS, 95% CI [0.02-0.98], **P* = .048; Table 6, Figure 1B). Lastly, there were no postoperative surgical site infections in either group.

Discussion

Despite advances in minimally invasive techniques for SDH, craniotomy is still considered the gold standard.¹⁸ With the advent and commercialization of drainage systems, however, kits such as the SEPS have gained popularity and are increasingly described in the literature, particularly over the past 5 years.^{4,15,17,19,20} Bedside procedures such as the SEPS provide an opportunity to avoid general anesthesia, and its hermetically sealed mechanism decreases the risk of infection—both critical advantages when treating a primarily elderly population who tend to be poor surgical candidates.¹¹ Our retrospective study corroborates the existing literature suggesting

Figure 1. A, Forest plot depicting β value and associated 95% confidence interval (CI) associated with subdural evacuating port system (SEPS) in multivariate linear regression for percent residual hematoma volume at 24-hour postintervention, cost of hospitalization, and length of hospital stay. Sign of the β value denotes the positive or negative association of the outcome with SEPS as compared to craniotomy. B, Forest plot depicting odds ratio (OR) and 95% CI associated with SEPS in multivariate logistic regression for postoperative seizure incidence and for recurrence (defined as requiring a reoperation). OR > 1 indicates association with SEPS, whereas OR < 1 indicates association with craniotomy.

Table 3. Two-Way ANOVA and Tukey Post Hoc Tests for Residual Hematoma Volume.^a

Parameter	F Statistic	P Value	
Hematoma age			
Acute/subacute versus chronic	1.93	.168	
Intervention			
Craniotomy versus SEPS	2.04	.156	
Interaction			
Hematoma age + intervention	4.62	.034^b	
	Mean Residual Volume at 24 hours (%)	95% CI	P Value (Tukey Post Hoc Test)
Acute/subacute SDH			
SEPS	45.60%	[32.5-58.6]	.851
Craniotomy	38.90%	[29.1-48.7]	
Chronic SDH			
SEPS	38.50%	[12.8-64.3]	.195
Craniotomy	71.60%	[51.3-91.8]	

Abbreviations: CI, confidence interval; SDH, subdural hematoma; SEPS, subdural evacuating port system.

^aAnalysis performed by 2-way analysis of variance (ANOVA), F statistic is given for each predictor variable and for the interaction, post hoc comparisons are performed by Tukey honest significance test.

^bSignificantly different for $\alpha = .05$.

that the SEPS is associated with a low postoperative infection and comorbidity rate with a 0% infection rate observed in our study across nearly 40 patients.^{14,15}

SEPS has been widely promoted in the literature as an efficacious alternative for evacuation of cSDH, but its use in acute or mixed density collections is controversial.^{16,21} Krieg

Table 4. Multivariate Linear Regression for Cost of Hospitalization.^a

Parameter	Univariate			Multivariate		
	β	95% CI	P Value	β	95% CI	P Value
Intervention						
SEPS versus craniotomy	−0.34	[−0.56 to −0.11]	.003 ^b	−0.34	[−0.54 to −0.13]	.002 ^b
Age	0.004	[−0.002 to 0.01]	.176	—	—	—
Gender						
Female versus male	−0.007	[−0.25 to 0.24]	.958			
Anticoagulation	0.46	[0.15 to 0.78]	.005 ^b	0.50	[0.21 to 0.80]	.001 ^b
Antiplatelet	0.05	[−0.19 to 0.28]	.702			
Statin	−0.23	[−0.46 to 0.005]	.055	—	—	—
INR	0.58	[0.21 to 0.96]	.003 ^b	—	—	—
PLT	−0.001	[−0.002 to 0.0001]	.072	−0.001	[−0.002 to −0.0002]	.024 ^b
Hematoma lateralization						
Left versus right	0.21	[−0.01 to 0.43]	.062	0.21	[0.01 to 0.41]	.037 ^b
Bilateral	0.004	[−0.25 to 0.26]	.973			
Hematoma age			.876			
Chronic versus acute/subacute	−0.02	[−0.30 to 0.26]				
Preoperative hematoma volume	0.001	[−0.007 to 0.008]	.801			
Preoperative midline shift	0.008	[−0.01 to 0.03]	.477			

Abbreviations: CI, confidence interval; INR, international normalized ratio; PLT, platelet count; SEPS, subdural evacuating port system.

^aAnalyses performed as described in Table 2.

^bSignificantly different for $\alpha = .05$.

Figure 2. Overlay histogram depicting the distributions for cost of hospitalization (in dollars) stratified by intervention (red—craniotomy, blue—subdural evacuating port system [SEPS]).

et al described a large cohort of 320 patients who underwent first-line TDC for subdural evacuation of any age or density on CT and found that TDC with hollow screw more effectively drained hyperdense and mixed density lesions within the first 24 hours, and some reviews have extrapolated this finding to SEPS.^{21,22} However, series studying SEPS specifically have found that hypodense or chronic collections are actually significantly less likely to recur than mixed density collections after SEPS intervention.^{16,23,24} Given these findings, subsequent SEPS studies have restricted their study

populations to patients with cSDH and found similar rates of recurrence in this subgroup (15%-24%) as in our series (12.5%).^{4,13,15,17,20} Acute and subacute hematomas treated with SEPS in our series trended toward having an increased 24-hour residual hematoma volume compared to chronic hematomas. Combined with our additional finding that SEPS was significantly less effective than craniotomy at preventing recurrence in acute and subacute hematomas, our data support the more recent, SEPS-specific, literature and cautions its use in more emergent, aSDH cases.

Several studies have additionally investigated the influence of intrahematoma septations on outcomes after SEPS; A single-center retrospective study of over 150 patients by Neal et al determined that cSDHs with greater than 2 septations were more likely to fail initial intervention with SEPS.²³ Kenning et al similarly attributed the relatively increased failure of SEPS in mixed-density hematomas to higher incidence of membranous septations.¹⁶ Limited data on intrahematoma septations in our study restrict the power of our conclusions on predictors of recurrence across SDH subtypes. Consensus remains that more invasive interventions should be employed to address highly septated collections.^{23,25}

Although there is general agreement that SEPS is safe and effective in most cSDH cases, few studies have compared relative cost and labor burdens of SEPS and other interventions. Our study showed that SEPS was associated with significantly decreased hospitalization costs ($P = .002$) and length of hospital stay ($P = .0002$) when compared with craniotomy, even after adjusting for multiple potentially influential factors such as anticoagulant use or INR on admission. Additionally, when

Table 5. Multivariate Linear Regression for Length of Stay.^{a,b}

Parameter	Univariate			Multivariate		
	β	95% CI	P Value	β	95% CI	P Value
Intervention						
SEPS versus craniotomy	−0.36	[−0.57 to −0.15]	.009 ^c	−0.38	[−0.57 to −0.13]	.0002 ^c
Age	0.006	[−0.0004 to 0.01]	.069	0.006	[0.00008 to 0.01]	.047 ^c
Gender						
Female versus male	0.09	[−0.14 to 0.32]	.448			
Anticoagulation	0.21	[−0.11 to 0.52]	.191	—	—	—
Antiplatelet	0.15	[−0.07 to 0.38]	.186	—	—	—
Statin	−0.15	[−0.37 to 0.08]	.196	—	—	—
INR	0.44	[0.08 to 0.81]	.019 ^c	0.43	[0.10 to 0.76]	.011 ^c
PLT	−0.0005	[−0.002 to 0.0007]	.412	—	—	—
Hematoma lateralization						
Left versus right	0.32	[0.12 to 0.53]	.003 ^c	0.33	[0.14 to 0.51]	.0008 ^c
Bilateral	0.10	[−0.14 to 0.35]	.413			
Hematoma age			.464			
Chronic versus acute/subacute	0.10	[−0.17 to 0.37]				
Preoperative hematoma volume	−0.001	[−0.009 to 0.006]	.707			
Preoperative midline shift	−0.01	[−0.03 to 0.01]	.328			

Abbreviations: CI, confidence interval; INR, international normalized ratio; PLT, platelet count; SEPS, subdural evacuating port system.

^aAnalyses performed as described in Table 2.

^b“—” indicates variable removed from multivariate regression due to insignificant contribution to overall model.

^cSignificantly different for $\alpha = .05$.

Table 6. Postintervention Complications.^a

Complication	Craniotomy, n (%)	SEPS, n (%)	Odds Ratio (OR); >1 Positively Associated With SEPS	95% CI	P Value
Required reoperation	9 (13.2)	13 (33.3)	3.28	[1.25 to 8.62]	.016 ^b
Subgroup Analysis: by Hematoma Age					
Acute/subacute			3.71	[1.31 to 10.51]	.011 ^b
Recurrence	8 (14.55)	12 (38.71)			
No recurrence	47 (85.45)	19 (61.29)			
Chronic			1.71	[0.09 to 31.92]	1.000
Recurrence	1 (7.69)	1 (12.50)			
No recurrence	12 (92.31)	7 (87.50)			
Postop seizure	12 (17.7)	1 (2.6)	0.12	[0.02 to 0.98]	.048 ^b
Infection	0	0	1	—	—

Abbreviations: CI, confidence interval; SEPS, subdural evacuating port system.

^aAnalysis performed by multivariate logistic regression for dichotomous variables; OR indicates association with SEPS. Effect modifiers with a P value of <.05 were included in the models for each outcome; Subgroup analysis is performed by χ^2 test of independence for multiple interventions.

^bSignificantly different between 2 intervention arms for $\alpha = .05$.

isolating and analyzing only the SEPS cases that required reoperation during the same index admission (n = 10 patients), cost of overall hospitalization (including the reoperation costs) was still equivalent to that of initial intervention with craniotomy ($P = .891$). SEPS was, therefore, more cost-effective even when taking into account those cases requiring further procedures. These results corroborate the findings of the only other study by Balser et al examining relative costs; in a comparison of SEPS versus BHC, a more minimally invasive comparator than craniotomy, SEPS proved to also be associated with significantly

lower hospitalization costs and length of stay.²² Importantly, in calculating cost burden, Balser et al additionally accounted both for readmission costs and for readmission length of stay.²² In another earlier study of TDC versus BHC from which we can extrapolate to SEPS, Smely et al found a 50% decrease in length of stay with a marked effect on cost savings associated with TDC.²⁶ Although readmission data were not included in our series, the combined data from these studies strongly suggest a critical logistical and cost advantage to intervention with SEPS for cSDH.

Another key finding of our study is that SEPS was associated with a significantly lower postoperative seizure rate than craniotomy ($P = .048$), despite standard postoperative 2-week antiepileptic prophylaxis with levetiracetam. Seizures are a common complication in SDH patients in general, with reported postacute SDH seizure incidences ranging from 24% to 36% and postchronic SDH incidences at 2.3% to 17%.²⁷⁻³⁰ Significant risk factors for seizure following aSDH include severity of injury characterized by preoperative Glasgow Coma Scale (GCS) less than 8, early postoperative GCS score less than or equal to 8, and a need for craniotomy.³¹ In chronic SDH, seizure risk factors include alcohol abuse, previous stroke, mental status changes, various specific CT findings, craniotomy, and lower GCS at discharge.³² The influence of type of surgical intervention on seizure incidence is uncertain. In patients with preoperative seizures, surgical intervention of any kind seems to improve seizure. At the same time, intervention itself is a significant risk factor for development of postoperative seizures.³⁰ Data from our study are in accordance with this observation, as preoperative seizure did not significantly influence the incidence of postoperative seizure across our patient population. Previous literature has shown that craniotomy is more strongly associated with postoperative seizures than BHC.³¹ The impact of craniotomy on postoperative seizure in SDH is attributed to increased cortical manipulation and likelihood of intraparenchymal injury inherent to open surgery.³⁰ The SEPS device, on the other hand, uniquely allows for drainage without transgression of the evacuating drain into the subdural space, which likely contributes to the decreased observed incidence of postoperative seizure.¹¹ Nevertheless, since the overall postoperative seizure incidence in our cohort was relatively low (13 of 107 patients, 12.15%) and follow-up periods varied across patients, further studies powered to specifically look at seizure outcomes after surgical intervention for SDH remain necessary to draw more generalizable conclusions.

Although our study was able to draw statistically significant conclusions suggesting SEPS as a cost-effective alternative to craniotomy, particularly in cSDH, the generalizability of our study is inherently limited by both its retrospective and single-center nature (with inherently relatively small sample size). Furthermore, our study period was limited to 5 years; more longitudinal studies have shown that cumulative physician experience with SEPS placement over time significantly lowers corresponding recurrence rates.^{15,17} Another key limitation is the variation in the extent of follow-up between the 2 intervention groups as the craniotomy group experienced nearly double the length of follow-up as the SEPS group. Although this may be reflective of the observed increased postoperative seizure rate or the general invasiveness of craniotomy requiring longer recovery time, it is important to consider that observed recurrence rates in the SEPS group may be confounded by a shorter follow-up period. Lastly, as previously discussed, cost and hospitalization length data from readmissions for SDH recurrence were not available in

our data set for cost-benefit analysis. However, our study is the first to adjust cost and length of stay outcomes from the index admission for potentially confounding variables related to patient presentation (age, blood thinner use, laboratory values, imaging features, etc) in multivariate analysis. Additionally, the added costs of intervention for recurrence in our SEPS patient population was, in fact, taken into account for 10 of 13 patients who required secondary intervention, as these 10 patients actually received secondary intervention during the index admission (only 3 patients were readmitted later in follow-up for further treatment). Based on our findings and extrapolating from existing evidence demonstrating the cost-effectiveness (accounting for all readmission costs) of SEPS over BHC, it is reasonable to conclude that SEPS is a truly cost-effective tool in the appropriate patient population.²²

Conclusion

The SEPS procedure is effective at reducing hematoma volume in SDH, and when used in cSDH, demonstrates comparable recurrence rates to traditional craniotomy. Intervention with SEPS also produces significantly lower costs and shortens length of hospital stay compared to the gold standard craniotomy. Additionally, SEPS carries a low morbidity profile and likely causes fewer postoperative seizures. Although this single-center, nonrandomized, retrospective study is relatively limited in size and nature, these findings encourage intervention with SEPS particularly for cSDH—especially in the elderly population and for other poor surgical candidates.

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Supplemental Material

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