



Original Article

## Puerto Rico Recurrence Scale: Predicting chronic subdural hematoma recurrence risk after initial surgical drainage

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### ABSTRACT

**Background:** Chronic subdural hematoma (CSDH) commonly affects older individuals and is associated with a relatively high rate of recurrence after surgery. Many studies have created grading systems to identify patients at high risk of CSDH recurrence after the initial surgery. However, no system has been adopted widely. The authors present the first CSDH grading system created from a population-based single-center data set.

**Methods:** A single-center Puerto Rican population-based retrospective analysis was performed on consecutive patients treated for a CSDH at a designated institution from July 1, 2017 to December 31, 2019. Univariate and multivariate analyses were used to create a CSDH recurrence grading scale. Retrospective validation was conducted on this sample population.

**Results:** The study included 428 patients. Preoperative midline shift, postoperative midline shift, and size of postoperative subdural space differed between the recurrence and nonrecurrence groups ( $P = 0.03$ ,  $0.002$ , and  $0.002$ , respectively). A multivariate analysis was used to create a 10-point grading scale comprising four independent variables. Recurrence rates progressively increased from the low-risk (0–3 points) to high-risk (8–10 points) groups (2.9% vs. 20.3%;  $P < 0.001$ ).

**Conclusion:** A 10-point grading scale for CSDH recurrence was developed with four components: preoperative midline shift ( $\leq 1$  and  $> 1$  cm), laterality (bilateral, unilateral-right, and unilateral-left), size of postoperative subdural space ( $\leq 1.6$  and  $> 1.6$  cm), and pneumocephalus (present or absent). Patients who scored higher on the scale had a higher risk of recurrence. This CSDH grading scale has implications for Puerto Rico and the general population as the elderly population increases worldwide.

**Keywords:** Chronic subdural hematoma, Grading scale, Puerto Rico, Recurrence, Subdural space

### INTRODUCTION

The topic of chronic subdural hematoma (CSDH) and its recurrence has recently gained much attention. CSDH is one of the most common conditions neurosurgeons treat, estimated to occur in 3.4–5 individuals/100,000.<sup>[4,7,14,19,20,31]</sup> CSDH is most common among the elderly population, and the incidence of CSDH increases with age (among those older than 65 years, 8–58 individuals/100,000 are affected).<sup>[4,7,14,19,20,31]</sup> CSDH is associated with a mortality rate of

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9.1% in the general population and up to 16.7% among those 65 years of age or older.<sup>[33]</sup> The incidence of CSDH and the associated mortality rate is expected to increase as the elderly population grows. Surgical considerations are germane because the percentage of patients with CSDH recurrence after initial surgery is relatively high (3–30% of cases).<sup>[36]</sup>

CSDH is strongly associated with neurotrauma, specifically minor head trauma. Head trauma is the most important risk factor for the development of CSDH, with 50–80% of patients in large studies having a history of head trauma before presentation.<sup>[28]</sup> The current pathophysiological understanding is that the subdural blood accumulation develops into a CSDH because of direct or indirect trauma to the cranium that causes the parasagittal bridging veins to tear.<sup>[22]</sup> The most common CSDH-related trauma involves a ground-level fall by an elderly patient. The risk of falls is the greatest among the elderly population. It has been estimated that about 30% of people 65 years of age or older fall at least once a year and approximately half of those individuals do so repeatedly.<sup>[27,28]</sup>

Studies have identified demographic, comorbid, preoperative, and postoperative factors associated with CSDH recurrence.<sup>[1,3,5,8,10-13,16-18,21,24,25,29,32-34,37,41,42,44]</sup> Examples include advanced age, bleeding tendency, brain atrophy, alcohol abuse, bilateral hematoma, hematoma density, size or volume of the hematoma, midline shift, diabetes mellitus, postoperative posture, postoperative subdural air accumulation, inflammatory cytokines, and some technical aspects of surgery. Identifying these factors allow clinicians to better manage patients deemed to be at high risk for recurrence. Unfortunately, inconsistencies exist in the evaluation of variables from study to study. For example, deviations are found in measuring hematoma size, hematoma volume, midline shift, and postoperative pneumocephalus.<sup>[33]</sup> As a result, the creation of a generalizable grading system has been challenging. At present, no grading system has been widely adopted for individual prediction of CSDH recurrence after the initial surgery. This study used a single-institution database that represents the population of Puerto Rico to create a CSDH grading system for recurrence risk.

## MATERIALS AND METHODS

### Study design

The study was approved by the University of Puerto Rico Medical Sciences Campus Institutional Review Board (A0230120). Due to the retrospective design of the study and the lack of patient identifiable information, patient consent was not obtained. Electronic medical records of patients who underwent operations at the Puerto Rico Medical Center between July 1, 2017, and December 31, 2019, were retrospectively analyzed. The study inclusion criteria were as

follows: age 18 years or older, CSDH diagnosed on computed tomography (CT), surgical management of CSDH, and preoperative and postoperative imaging performed at our institution. Exclusion criteria were missing preoperative or postoperative CT imaging and CT images with motion artifacts. A total of 833 patient records with the diagnosis of CSDH were reviewed; 428 patients met the study criteria and were included in the analysis. Both unilateral and bilateral hematoma cases were included in the analysis. Detailed information on medications used in the preoperative or postoperative management of CSDH (i.e., dexamethasone, atorvastatin, or tranexamic acid) was not included in the analysis.

All patients underwent surgical evacuation through a burr hole or craniotomy. If a patient required both burr hole and craniotomy drainage, the patient was assigned to the craniotomy group. If a patient presented with bilateral hematomas ( $n = 177$ ) but underwent a unilateral operation, they were not included in the bilateral procedure group (61 patients who presented with bilateral hematomas were not included in the bilateral procedure group [ $n = 116$ ]). Saline irrigation was used in all patients. Postoperative drainage was used at the discretion of the attending neurosurgeon.

All imaging data were obtained using the hospital's picture archive and communication system (Carestream Vue Motion Software; Carestream, Inc., Rochester, NY). Postoperative imaging was performed on postoperative day 1. All imaging was performed with a standard CT machine and no images were obtained using a portable CT scanner. Patients who had images with motion artifacts were excluded from the study. Patients were added to the recurrence group if they fulfilled all of the following conditions: (1) reaccumulation of blood within the postoperative hematoma cavity on follow-up CT, (2) reappearance of neurological symptoms, (3) diagnostic imaging conducted at our institution, and (4) another surgical intervention at our institution. Patients who had CSDH in the postoperative space on repeat imaging but did not become symptomatic or require surgery were not considered to have had a recurrent CSDH.

### Radiographic measurements

Quantitative measurements were obtained for all preoperative and postoperative images using the hospital's picture archive and communication system. All measurements (in centimeters) were taken by a single neurosurgeon and verified by a neuroradiologist, both of whom were masked as to whether a patient belonged to the recurrence or nonrecurrence group.

Preoperative and postoperative midline shifts were determined by drawing a line from the anterior and posterior attachments of the falx cerebri and measuring the maximal

perpendicular distance of the septum pellucidum from this line, usually at the level of the foramen of Monroe, if identifiable. The size of the CSDH was defined as the maximal thickness of hematoma from the inner table of the skull to the surface of the brain in the axial view. If a patient had bilateral hematomas, the size of the CSDH refers to the larger of the two hematomas. The size of the postoperative subdural space was defined as the maximal thickness of subdural space from the inner table of the skull to the surface of the brain in the axial view. For patients who underwent a bilateral procedure, the postoperative subdural space refers to the larger of the two subdural spaces. For sizes of CSDH and postoperative subdural space, measurements were not acquired in the cranial convexity in order to prevent overestimation of distance. Examples of CSDH size, preoperative midline shift, and size of the postoperative subdural space are shown in Figure 1.

### Statistical analysis and grading-scale creation

Stata/MP 15.1 software (StataCorp LP, College Station, TX, USA) was used for the statistical analyses. Most variables exhibited skew or kurtosis, necessitating the reporting of medians instead of means in the descriptive statistics. The Chi-square test was used to assess the differences in categorical variables between patients whose CSDH recurred (recurrence) and patients whose CSDH did not recur (nonrecurrence). For the continuous variables, Mann-Whitney *U* tests or *t*-tests were used to evaluate the differences between medians and means, respectively.

Variables with  $P < 0.20$  in univariate analyses were tested for inclusion in a multivariate logistic regression model. The logistic regression model provided odds ratios (ORs) with 95% confidence intervals and  $\beta$  regression coefficients. A receiver operating characteristic (ROC) curve was created from the

multivariate logistic regression model. The area under the curve (AUC) and corresponding 95% confidence intervals were calculated. The continuous variables' cutoff point values were calculated using CUTPT.<sup>[9]</sup> Points were assigned proportionally to the  $\beta$  coefficients to create a predictive scale of the recurrence of CSDH using the cutoff point values for the contributing continuous variables and the presence or absence of a characteristic from the contributing categorical variables.

## RESULTS

### Patient characteristics

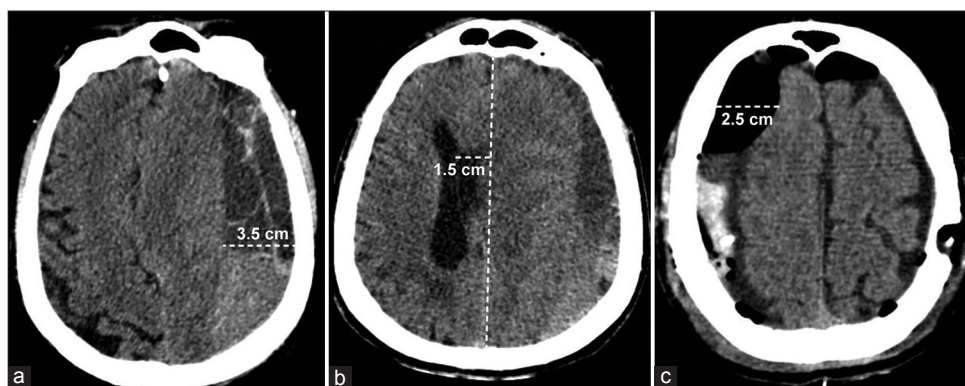
We identified 428 patients with CSDH who met the inclusion criteria. Table 1 shows descriptive statistics of the patients. Recurrence was identified in 45 (10.5%) of the patients (36 of 304 [11.8%] men and nine of 124 [7.3%] women).

### Univariate analysis

Table 1 includes univariate analyses comparing the characteristics of patients with versus without CSDH recurrence. The median size of preoperative midline shift and postoperative subdural space size was higher in the recurrence group than in the nonrecurrence group ( $P \leq 0.03$ ). Right-sided laterality occurred in 17.8% (8/45) of patients with CSDH recurrence and 30.8% (118/383) of patients without recurrence ( $P = 0.09$ ). Twenty-three of 45 patients (51.1%) in the recurrence group presented with bilateral hematomas versus 154 of 383 (40.2%) in the nonrecurrence group ( $P = 0.16$ ).

### Multiple logistic regression analysis

Multivariate logistic regression results are shown in Table 2. Larger postoperative subdural space, larger size



**Figure 1:** Examples of quantitative variables in the study cohort were measured on axial CT images. (a) Measurement of the size of chronic subdural hematoma (CSDH) in a patient presenting with unilateral-left CSDH. (b) Measurement of the preoperative midline shift in a patient presenting with unilateral-left CSDH. (c) Measurement of the size of postoperative subdural space in a patient presenting with bilateral CSDH who also underwent a bilateral procedure. The white dashed line indicates the measured distance. *Used with permission from Centro Médico de Puerto Rico, Administración de Servicios Médicos de Puerto Rico, San Juan, Puerto Rico.*

**Table 1:** Clinical and demographic characteristics of patients with CSDH, with and without recurrence.

Characteristic	All patients (n=428)	CSDH Recurrence (n=45)	No CSDH Recurrence (n=383)	P value
Sex				0.16
Male	304 (71.0)	36 (11.8)	268 (88.2)	
Female	124 (29.0)	9 (7.3)	115 (92.7)	
Age, mean (SD), years	75.0 (11.4)	74.0 (11.2)	75.2 (11.4)	0.51
Procedure				
Burr hole	396 (92.5)	42 (10.6)	354 (89.4)	0.83
Craniotomy	29 (6.8)	2 (6.9)	27 (93.1)	0.51
Both	3 (0.7)	1 (33.3)	2 (66.7)	0.20
Laterality				
Bilateral	177 (41.4)	23 (13.0)	154 (87.0)	0.16
Unilateral-left	125 (29.2)	14 (11.2)	111 (88.8)	0.77
Unilateral-right	126 (29.4)	8 (6.3)	118 (93.7)	0.07
Size CSDH, median (IQR), cm	2.2 (1.8–2.7)	2.4 (1.9–2.9)	2.2 (1.8–2.7)	0.09
Preoperative midline shift, median (IQR), cm	0.8 (0.5–1.3)	1 (0.5–1.6)	0.8 (0.5–1.2)	0.03
Postoperative subdural space size, median (IQR), cm	1.5 (1.1–1.9)	1.7 (1.3–2.3)	1.5 (1.1–1.9)	0.002
Postoperative midline shift, median (IQR), cm	0.5 (0.2–0.7)	0.6 (0.4–0.9)	0.5 (0.2–0.6)	0.002
Density				
Heterogeneous	162 (37.9)	16 (9.9)	146 (90.1)	0.74
Hypodense	227 (53.0)	22 (9.7)	205 (90.3)	0.56
Isodense	39 (9.1)	7 (17.9)	32 (82.1)	0.11
Membranous septation on CT				0.41
Present	261 (61)	30 (11.5)	231 (88.5)	
Absent	167 (39)	15 (9)	152 (91)	
Hematocrit effect				0.09
Present	177 (41.4)	24 (13.6)	153 (86.4)	
Absent	251 (58.6)	21 (8.4)	230 (91.6)	
Bilateral procedure				0.52
Yes	116 (27.1)	14 (12.1)	102 (87.9)	
No	312 (72.9)	31 (9.9)	281 (90.1)	
Postoperative drain				0.68
Present	362 (84.6)	39 (10.8)	323 (89.2)	
Absent	66 (15.4)	6 (9.1)	60 (90.9)	
Postoperative pneumocephalus				0.08
Present	404 (94.4)	45 (11.1)	359 (88.9)	
Absent	24 (5.6)	0 (0)	24 (100)	
Mount Fuji sign				0.07
Present	43 (10)	8 (18.6)	35 (81.4)	
Absent	385 (90)	37 (9.6)	348 (90.4)	
Postoperative acute subdural hematoma				0.11
Present	119 (27.8)	17 (14.3)	102 (85.7)	
Absent	309 (72.2)	28 (9.1)	281 (90.9)	
Postoperative intraparenchymal hematoma				0.19
Present	14 (3.3)	0 (0)	14 (100)	
Absent	414 (96.7)	45 (10.9)	369 (89.1)	
Antiplatelet, anticoagulant use				0.31
Yes	123 (28.7)	10 (8.1)	113 (91.9)	
No	305 (71.3)	35 (11.5)	270 (88.5)	

IQR: Interquartile range, SD: Standard deviation, CSDH: Chronic subdural hematoma. Data are no. (%) unless otherwise indicated. The percentages shown for all patients are calculated for the total patient population; those shown for the recurrence and nonrecurrence groups are calculated using the total patients in the variable category

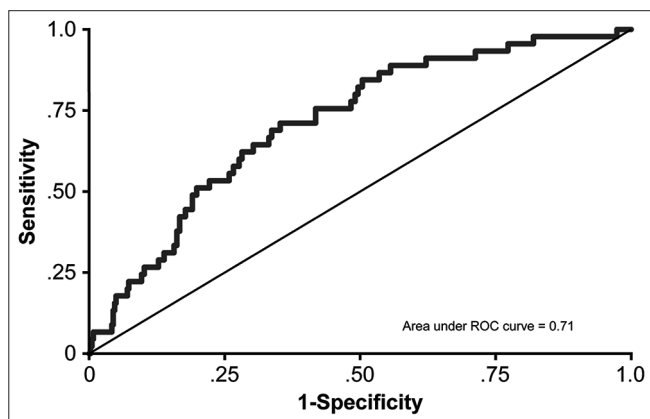
of preoperative midline shift, and bilaterality significantly contributed to explaining the variation in CSDH recurrence among patients ( $P \leq 0.03$ ).

The overall AUC for the model was 0.71, categorizing it as a fair predictor.<sup>[30]</sup> Figure 2 shows the ROC curve for the model described in Table 2.

**Table 2:** Multivariate logistic regression: Characteristics associated with recurrence of chronic subdural hematoma.

Characteristic*	Odds Ratio (95% CI)	$\beta$ (95% CI)	P value	AUC
Postoperative subdural space size, cm	1.94 (1.2–3.1)	0.66 (0.19–1.1)	0.01	0.71
Preoperative midline shift <sup>†</sup> , cm	2.32 (1.2–4.3)	0.84 (0.2–1.5)	0.01	
Bilaterality	2.8 (1.1–7.0)	1.0 (0.1–2.0)	0.03	
Unilateral–left <sup>‡</sup>	1.8 (0.7–4.6)	0.6 (-0.4–1.5)	0.21	

AUC: Area under the curve,  $\beta$ : Logit model regression coefficient. AUC is for the overall model. \*Postoperative pneumocephalus was not included in the multivariate modeling due to its presence in most cases but was included in the calculation of the grading-scale score. <sup>†</sup>Because preoperative and postoperative midline shifts were correlated (Pearson correlation coefficient: 0.691,  $P < 0.001$ ), only preoperative midline shift was included in the regression model. <sup>‡</sup>Although the absence of right-sided laterality was not significant in the univariate test ( $P = 0.07$ ), a set of dummy variables representing bilaterality and unilaterality (bilaterality, unilateral-right, and unilateral-left) was included in the multivariate model as bilateral and unilateral-left, with unilateral-right excluded as the reference category



**Figure 2:** Receiver operating characteristic (ROC) curve for the multivariate model: ROC curve of the four factors obtained from the multivariate logistic regression model. Used with permission from Barrow Neurological Institute, Phoenix, Arizona.

### Internal validation and model use

Table 3 shows AUC values for each variable in the multivariate regression model and their associated cutoff values.<sup>[23,40]</sup> Figure 3 shows the ROC curves for the continuous variables in the model.

Table 4 shows the predictive grading scale from cutoff values applied proportionally according to the  $\beta$  coefficient size and the reported CSDH recurrence rate by score. Figure 4 displays logistic regression results when the model is applied retrospectively to the patient data.

## DISCUSSION

This report is the first of a predictive CSDH recurrence grading scale developed on the basis of a single population data set, to the best of our knowledge. In addition, this study presents the largest sample size used to develop any CSDH recurrence prediction system (see Table 5 for a summary of other systems).<sup>[2,16,33,39,43]</sup>

The derived scale may have utility in managing patients undergoing surgical evacuation of CSDH. Patients with

**Table 3:** Receiver operating characteristic curve characteristics of included factors and cutoff values.

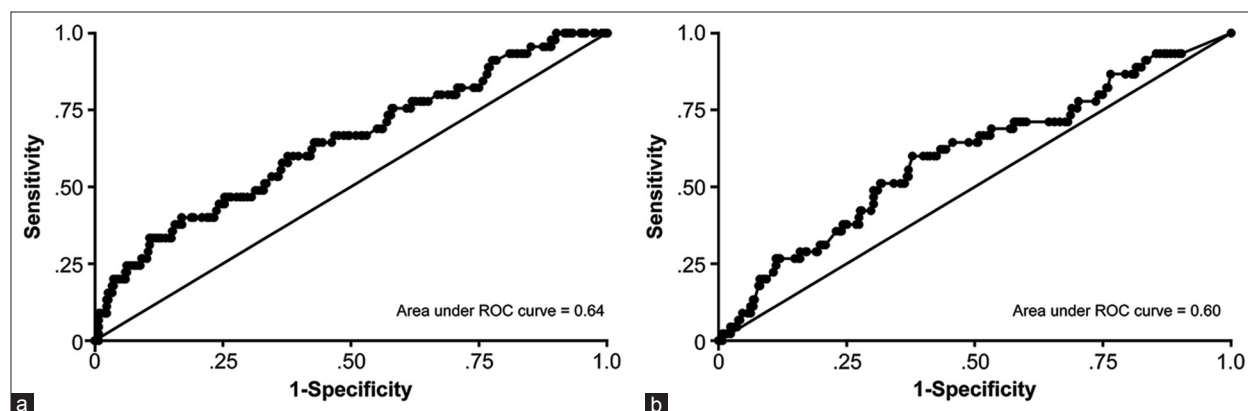
Characteristic	AUC (95% CI)	SE	Cutoff Value
Postoperative subdural space size	0.64 (0.55–0.73)	0.045	1.6
Preoperative midline shift	0.60 (0.51–0.69)	0.047	1.0
Bilaterality	0.56 (0.48–0.63)	0.040	N/A
Laterality-left	0.51 (0.44–0.58)	0.037	N/A

AUC: Area under the curve, N/A: Not applicable, SE: Standard error. Cutoff values were determined using the Liu method<sup>[23,40]</sup>

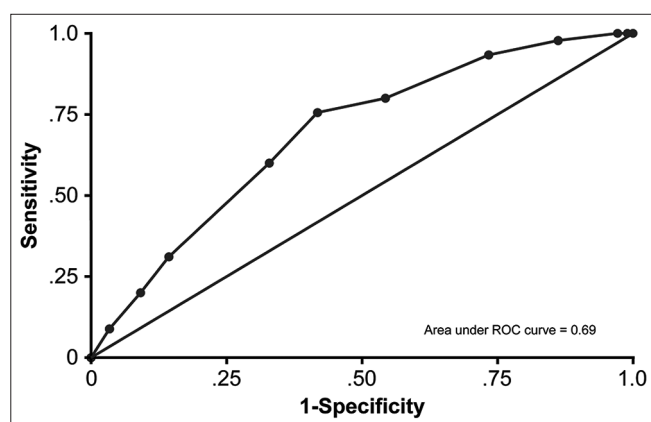
**Table 4:** Predictive scale for recurrence of chronic subdural hematoma and internal validation results.

Variable	Scale Points	No. (%) of Patients with Recurrence	P value
Scale component			
Laterality			
Bilateral	2		
Unilateral-left	1		
Unilateral-right	0		
Preoperative midline shift			
>1.0 cm	3		
≤1.0 cm	0		
Postoperative subdural space size			
>1.6 cm	3		
≤1.6 cm	0		
Postoperative pneumocephalus			
Yes	2		
No	0		
Internal validation			
Low risk (n=102)	0–3	3 (2.9)	<0.001
Moderate risk (n=226)	4–7	28 (11.0)	
High risk (n=55)	8–10	14 (20.3)	

higher scores could be at greater risk of recurrence. Our study findings may be extrapolated to the treatment centers that



**Figure 3:** Receiver operating characteristic (ROC) curve for the univariate analysis. (a) Size of postoperative subdural space and recurrence. (b) Preoperative midline shift and recurrence. Used with permission from Barrow Neurological Institute, Phoenix, Arizona.



**Figure 4:** Receiver operating characteristic (ROC) curve for the retrospective application of scale to the data set. ROC curve for the univariate analysis of the scale and recurrence. Used with permission from Barrow Neurological Institute, Phoenix, Arizona.

care for an older population. This grading system could be used to standardize patient care, improve enrollment criteria for clinical trials, determine whether a patient would benefit from adjuvant treatment (i.e., middle meningeal artery embolization), and provide reliable criteria for assessing new treatment strategies.

#### Factors associated with recurrence and subdural space

The univariate analysis showed that the preoperative midline shift, postoperative subdural space size, and postoperative midline shift differed significantly between the two study groups. Other studies have reported similar results.<sup>[8,11,17,25,32,34,41]</sup> Our study is unique because it measured subdural space instead of postoperative hematoma thickness. This distinction is key because the postoperative subdural space can be occupied by residual hematoma, acute blood, cerebrospinal fluid, air, and saline solution. For example, air is reportedly associated with CSDH recurrence<sup>[15,38,44,46]</sup> and

can occupy a significant amount of space. Sloan<sup>[35]</sup> suggested that the volume of air accumulated postoperatively can range from 6 to 280 cm<sup>3</sup>. Therefore, all subdural components should be incorporated in both measurement and analysis. Measuring only postoperative hematoma thickness is insufficient for risk stratification.

Increased postoperative subdural space size contributes to CSDH recurrence for many reasons. First, it allows blood to reaccumulate, and, in some cases (i.e., subdural pneumocephalus), it provides a low-pressure environment. Second, it suspends the brain and puts bridging veins at a higher risk of tearing. Finally, it prevents the adhesion between the inner and outer neomembranes created by the CSDH where adhesion of the inner and outer neomembranes is believed to be necessary for CSDH cure.<sup>[26]</sup>

A persistent postoperative subdural space reflects poor brain expansion that occurs with advanced age and atrophy. As patients get older, their brains lose elasticity and cannot adequately expand after being compressed. Brain atrophy is an independent factor that contributes to CSDH recurrence.<sup>[45]</sup> Regarding CSDH grading scales, Shen *et al.*<sup>[33]</sup> used severe brain atrophy as a component in their scale. Although we did not directly measure or describe the effects of age, we agree that advanced age and brain atrophy contributed to the persistent or increased subdural space in our patient sample.

#### Previous grading scales for CSDH recurrence

Five CSDH recurrence or risk grading systems have been proposed.<sup>[2,16,33,39,43]</sup> The components of each grading system are described in Table 5. The sample size for each scale is smaller than the cohort used in our study. In addition, none of the previous grading scales were constructed based on data from a single-population study.

Our study devised a grading system similar to others that use laterality (i.e., bilateral vs. unilateral), preoperative midline

**Table 5:** Previously published CSDH recurrence grading systems.

Study	Grading System	Publication date	Laterality (sample size)	Components
Jack <i>et al.</i> <sup>[16]</sup> Stanišić <i>et al.</i> <sup>[39]</sup>	Oslo chronic subdural hematoma grading system	January 2015 March 2017	Unilateral (331) Both (107)	Age, CSDH volume, and hematoma septations Density on CT*, preoperative volume, and postoperative residual cavity volume
Shen <i>et al.</i> <sup>[33]</sup>		November 2019	Unilateral (342)	Antiplatelet or anticoagulant use, severe brain atrophy, age, postoperative pneumocephalus volume/postoperative hematoma cavity volume, drainage volume, and midline shift
Won <i>et al.</i> <sup>[43]</sup>	Modified Oslo chronic subdural hematoma grading system	February 2020 <sup>‡</sup>	Unilateral (272); bilateral (177)	Unilateral: Density on CT*, preoperative volume, postoperative residual cavity volume, and postoperative seizure; bilateral: Density on CT*, postoperative volume unilateral, postoperative air trapping unilateral, and postoperative seizure
Amoo <i>et al.</i> <sup>[2]</sup>	Dublin score derived	July 2021	Both (142)	Preoperative maximal hematoma thickness, age, and unilateral/bilateral appearance <sup>†</sup>

CSDH: Chronic subdural hematoma, CT: Computed tomography. \*Isodense or hyperdense subtypes and laminar or separated types versus hypodense or gradation subtypes and trabecular type. †Hypodense or isodense versus hyperdense or mixed density. ‡Publication date reflects epub ahead of print

shift, and postoperative pneumocephalus (i.e., postoperative air trapping). However, our use of postoperative subdural space size is unique. Our scale differs from other scales. It does not incorporate age, use of antiplatelet or anticoagulant agents, presence or absence of septations, hematoma appearance on CT (i.e., hematoma density), severe brain atrophy, postoperative seizures, drainage volume, the volume of the postoperative cavity, postoperative hematoma density, or fraction of postoperative pneumocephalus volume to postoperative hematoma cavity volume.

Our grading system comprises variables that were significantly and nonsignificantly different between the study groups — not all significant variables were included in the model. In addition, the model does not include some study variables that were used as components in the previous grading systems (e.g., age, anticoagulant or antiplatelet use, visible membranous septations, or hematoma density). We do not include them for two reasons. First, significant variables that were highly correlated with one another (e.g., preoperative and postoperative midline shift) cannot both be included in the study. The fitting of a multivariate model requires that the variables be independent. Thus, only the best-fit variable was used. Second, using multivariate logistic regression, the best combination of variables that explains the variance between our study groups was used to create our grading scale. In other words, our combination of four independent variables best explained the variation between recurrence and nonrecurrence of CSDH. The study variables used in the previous grading systems were evaluated and did not produce a significant model in our study population.

### Benefits of the Puerto Rico Recurrence Scale

The unique components of our grading scale are the specification of the right and left in laterality and the size of the postoperative subdural space (i.e., the maximal thickness of subdural space from the inner table of the skull to the surface of the brain in the axial view). Although other scales incorporate laterality as a component, none consider the side of a unilateral hematoma. In our study, the left-sided hematoma recurrence was more prevalent than right-sided hematoma recurrence, which was used as a component of our scale (unilateral-left = 1 point). A possible explanation for this prevalence is that the surgeons treated the left side with more caution during surgery because the left hemisphere of the brain is dominant in most patients. Greater caution by the surgeon could result in inadequate drainage and a larger residual space.

Earlier studies have emphasized consideration of the subdural space (i.e., postoperative or hematoma cavity)<sup>[2,16,33,39,43]</sup> but most measured volume instead of size, as in our system (i.e., maximal thickness). Like Amoo *et al.*,<sup>[2]</sup> we believe that this maximal thickness measurement is more intuitive and relevant because it is a single measurement. In addition, larger maximal thickness implies a great degree of cortical deformation, resulting in greater residual capacity with slower and incomplete brain expansion.<sup>[2]</sup> Therefore, we believe that measuring subdural space thickness is applicable in the hospital setting because it can be measured quickly and gives information regarding the potential space that could exist after surgery.

Our proposed grading system is potentially superior to other scales for several reasons. First, our scale was developed

using a large and single population-based data set. Therefore, the results are generalizable to other populations. Second, the study was conducted at a single center, thereby eliminating potential intercenter differences in the data. Third, our system is applicable to both unilateral and bilateral CSDH cases. Fourth, we showed that this scale has clinical value when applied retrospectively to a large sample population. Our grading system produced an AUC of 71%, which exactly mimics the AUC of the scoring system devised by Amoo *et al.*<sup>[2]</sup> (i.e., the Dublin score-derived system).

### Limitations

Some limitations apply to the study. The operations were performed by five different surgeons, and the results could vary between surgeons. Our definition of CSDH recurrence is not common to all CSDH studies. Thus, some patients with radiographic evidence of recurrence who did not undergo surgery were excluded from the study. As a result, there is a potential for selection bias. Our measurement of certain variables (e.g., size of the CSDH and midline shift) might differ from those used in other studies and thus lead to differences when comparing studies. The study is retrospective and long-term follow-up data are lacking.

In addition, there are important limitations that affect some parameters used in this study. First, abuse of alcohol was cited earlier as a possible risk for recurrence. The Puerto Rican population is known to have a high rate of alcohol abuse disorder (AUD) according to the DSM-V, especially among older men (36% of men over the age of 50 have AUD).<sup>[6]</sup> Abuse of alcohol could not be assessed in this study due to the lack of detailed reporting of patient alcohol consumption.

The use of a postoperative drain affects the volume of the subdural space. Some neurosurgeons prefer not to use a drain. Therefore, this study might not characterize the amount of subdural space and risk of recurrence due to neurosurgeon technique preferences.

Data regarding patient-specific coagulopathy were not available for many patients in this study. Thus, its association with CSDH could not be determined.

Although the presence of pneumocephalus correlated with CSDH recurrence in this study, the volume of pneumocephalus was not measured and analyzed. It makes intuitive sense that a larger amount of intracranial air, hence subdural space, could increase the risk of CSDH recurrence. These parameters are limited due to the retrospective nature of the study and a focus on other radiographic findings.

Specific medications used in the preoperative or postoperative management of patients (e.g., dexamethasone, atorvastatin, and tranexamic acid) were not considered in the

present study. In many cases, detailed records of medications were unavailable.

### CONCLUSION

CSDH is one of the most common neurosurgical pathologies and the rate of recurrence is high despite advances in the practice of neurosurgery. At present, there is no widely adopted grading system to predict CSDH recurrence. Our study proposes a novel scoring system (i.e., the Puerto Rico Recurrence Scale) developed through a single population-based sample at a single institution devoted to neurosurgical management of such patients. The scale has four components: laterality, preoperative midline shift, postoperative subdural space size, and postoperative pneumocephalus. The unique components of the proposed scale comprise the side of the brain in unilateral CSDH and measurement of the postoperative subdural space, which is intuitive, relevant, and rapidly measurable. Patients who score higher on the scale are at greater risk of recurrence and could benefit from adjuvant treatment and more intensive surveillance.

### Declaration of patient consent

Patients' consent not required as patients' identities were not disclosed or compromised.

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Nil.

### Conflicts of interest

There are no conflicts of interest.

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