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# A Reliable Grading System for Prediction of Chronic Subdural Hematoma Recurrence Requiring Reoperation After Initial Burr-Hole Surgery

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**BACKGROUND:** There is no widely adopted grading system for the prediction of postoperative recurrence requiring reoperation (RrR) in patients with chronic subdural hematoma (CSDH).

**OBJECTIVE:** We developed a CSDH grading system to predict RrR based on predictive characteristics that can be objectively assessed at the time of first presentation and initial surgery.

**METHODS:** Prospectively collected data from 107 consecutive surgical patients with CSDH were reviewed. Predictors of RrR were identified via logistic and lasso regression analyses. A prognostic CSDH grading system was proposed, with the weighing of predictors based on strength of association. The scoring system was then applied to the same set of patients in our database for internal validation.

**RESULTS:** The strongest predictors of RrR were an isodense or hyperdense lesions and laminar or separated lesions, and a postoperative CSDH cavity volume greater than 200 mL. The moderate predictors of RrR were a postoperative CSDH cavity volume of 80 to 200 mL and a preoperative CSDH volume greater than 130 mL. According to the prognostic CSDH grading system, no patients with a score of 0 points had RrR. RrR was observed in 6% of patients with a score of 1 to 2 points, 30% of patients with a score of 3 to 4 points, and 63% of patients with a score of 5 points (ie, the maximum score). The rate of RrR increased steadily with increases in the prognostic CSDH grading score ($P < .001$).

**CONCLUSION:** The prognostic CSDH grading system is an applicable tool for RrR risk stratification in patients with CSDH.

**KEY WORDS:** Chronic subdural hematoma, Prognostic grading system

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Surgical management is the preferred initial treatment option for patients with chronic subdural hematoma (CSDH) when mass effect results in clinical symptomatology. Postoperative recurrence requiring reoperation (RrR) remains a crucial problem associated with current surgical treatment and occurs in 2.5% to 33% of cases.[1-4]

**ABBREVIATIONS: CI,** confidence interval; **CSDH,** chronic subdural hematoma; **CT,** computerized tomography; **ROC,** receiver-operating characteristic; **RrR,** recurrence requiring reoperation; **V1,** preoperative CSDH volume; **V2,** postoperative volume of CSDH cavity after drainage removal

Inconsistencies regarding a variety of factors potentially precipitating CSDH RrR across numerous studies contribute that there is no widely adopted grading system for individual prediction of postoperative RrR that can be used in clinical treatment and clinical research. Furthermore, lack of a prognostic grading system, which can be used as part of standardized clinical assessment of patients with CSDH, contributes to inconsistency in clinical care and enrollment criteria for clinical research, failure to render objective criteria for assessing efficacy of treatment strategies, and comparisons of treatment efficacy between clinical studies.

The purpose of this study was to develop a CSDH grading system of postoperative RrR based on predictive factors that can be

objectively assessed at the time of first presentation and initial surgical treatment, which can be used as part of standardized clinical assessment of patients with CSDH.

## METHODS

The study was approved by the Regional Ethical Committee of Health Region South-East Norway (S-06281a) for the study of human subjects. Written informed consent was obtained from the patients or their close relatives before study inclusion.

This single-center prospective trial consisted of 107 consecutive adult surgical patients with symptomatic CSDH operated on between January and December 2008. The included patients were the same as those from 2 previous reports.[5,6] However, on this occasion the analysis consisted not only of additional statistical analyses and further stratification based on computerized tomography (CT) scan features, but also of assessments of demographic, clinical, and surgical characteristics from the time of initial presentation and initial surgery.

Thirty-four percent (36/107) of patients received antiplatelet therapy and 14% (15/107) received anticoagulant therapy. Any pre-existing antiplatelet or anticoagulant therapy was temporarily discontinued upon admission (except in 2 patients with mechanical heart valves) and re-established 4 weeks after surgery. If the preoperative international normalized ratio was more than 1.5 in any patient receiving anticoagulant therapy, the medication effect was reversed before surgery (vitamin K was administered to 12 patients, and prothrombin concentrate was administered to 7 patients).

CSDH was diagnosed by high-resolution CT scan on the day of surgery (GE Healthcare, Little Chalfont, United Kingdom; flip angle of 15 degrees, volume uptake based on 0.625-mm sectional view which was presented as axial slice thickness 2 mm, coronal slice thickness 3 mm, and sagittal slice thickness 3 mm) and confirmed by operative findings. All hematomas were classified into 4 types according imaging appearance based on density changes as described by Nakaguchi et al[7] and as illustrated in Figure: homogeneous, laminar, separated, and trabecular. The homogenous type was defined as a hematoma that exhibited a homogenous density (hypo-, iso-, or hyperdense subtypes). The laminar type was defined as a hematoma that has the high-density laminar structure running along the inner membrane that is considered to consist of fresh blood originated from the hematoma membrane. The separated type was defined as a hematoma containing 2 components of different densities, a lower density component located above a higher density component with a clear boundary lying between them. A normal head motion cannot homogenize these components. If the boundary was indistinct, with the low density and high density being mingled at the border, this was called the gradation subtype. In the gradation subtype, mild head movement causes homogenization of the hematoma. The trabecular type was defined as a hematoma with inhomogeneous contents which features high-density septa, created by fibrosis, running between the inner and outer membrane on a low-density to isodense background. Patients with bilateral CSDHs that exhibit the different types or subtypes of lesions were classified according to the density appearance which reflects the greater bleeding tendency. Follow-up CT scans of every patient were performed 1 day postoperatively when the drain was removed, and subsequently at monthly intervals until total disappearance of the hematoma used the same CT scan and the same imaging parameters as preoperatively. Estimation of pre- and postoperative lesion volumetric data was performed with the computer-assisted quantification method by a neuroradiologist, 2 neurosurgeons, and a physician specialist in neuroimaging postprocessing, who all were blinded to patients clinical condition, as described previously.[5,6]

The CT scan findings of CSDH that were assessed in this analysis included (1) imaging appearance based on density changes, (2) preoperative volume of the lesion ($V_1$; ie, 1 side in unilateral hematomas and the summation of both sides in bilateral hematomas), and (3) postoperative volume of the residual hematoma cavity on the first postoperative day after removal of the drain ($V_2$; ie, the sum of residual rinsing fluid and residual air volume in the hematoma cavity of 1 side in unilateral hematomas, and the summation of both sides in bilateral hematomas).

All patients underwent surgery procedure under local anesthesia and propofol sedation. Hematoma evacuation was performed by a single burr-hole, irrigation of the cavity, and closed-system drainage for 24 h. In the separated type of CSDH, efforts were made to open the septation via the enlarged single burr-hole so that both compartments were irrigated and drained. Patients with bilateral CSDHs received surgery bilaterally in the same manner and in 1 procedure. Postoperatively, patients remained on bed rest and lying flat until the drain was removed.

If serial CT scans during the 6-month follow-up period revealed increased subdural collection and brain compression on the operated side compared with the CT findings after removal of the drain, and if preoperative clinical symptoms and signs persisted or recurred, a CSDH relapse was diagnosed. So, the diagnosis of relapse was based on postoperative presence of the clinical symptoms and signs attributable to the CT scan signs of ipsilateral reaccumulation and brain compression (qualitatively assessed cortical and ventricular compression with intact, partly or globally compressed basal cisterns, and without or with midline displacement). Asymptomatic postoperative reaccumulation of hematoma, detected by CT scanning, was considered nonsurgical. All patients with a diagnosed CSDH relapse had lateralizing neurology and/or cognitive dysfunction and underwent reoperation. Therefore, the rate of reoperation was a real reflection of the underlying pathology. Thus, the recurrence rate was defined as the rate of reoperation to treat recurrent CSDH.

A CSDH RrR prognostic grading system (institutionally named the Oslo CSDH Scale) was developed, with the weighing of independent predictors based on strength of association.

### Statistical Analyses

Data were described using means (standard deviations) and numbers of patients (percentages) for continuous and categorical variables, respectively. The relationship between the investigated characteristics and RrR for CSDH was first assessed by the use of the independent sample *t*-test or chi-squared test, as appropriate.

Univariable and multivariable linear regression analyses were performed to assess the relationship between age over 80 years, male gender, history of brain infarction, and the $V_1$ and $V_2$ subgroups. Analyses were also performed to assess the association between the subgroup of $V_1$ measuring more than 130 mL and the subgroups of $V_2$ ranging from 80 to 200 mL and above 200 mL.

Univariable and multivariable logistic regression analyses on RrR initially included all potential predictor variables. Their predictive abilities were assessed using receiver-operating characteristic (ROC) curves. The results of the analysis for each variable and its relation to RrR for CSDH in the final model were presented as an odds ratio with

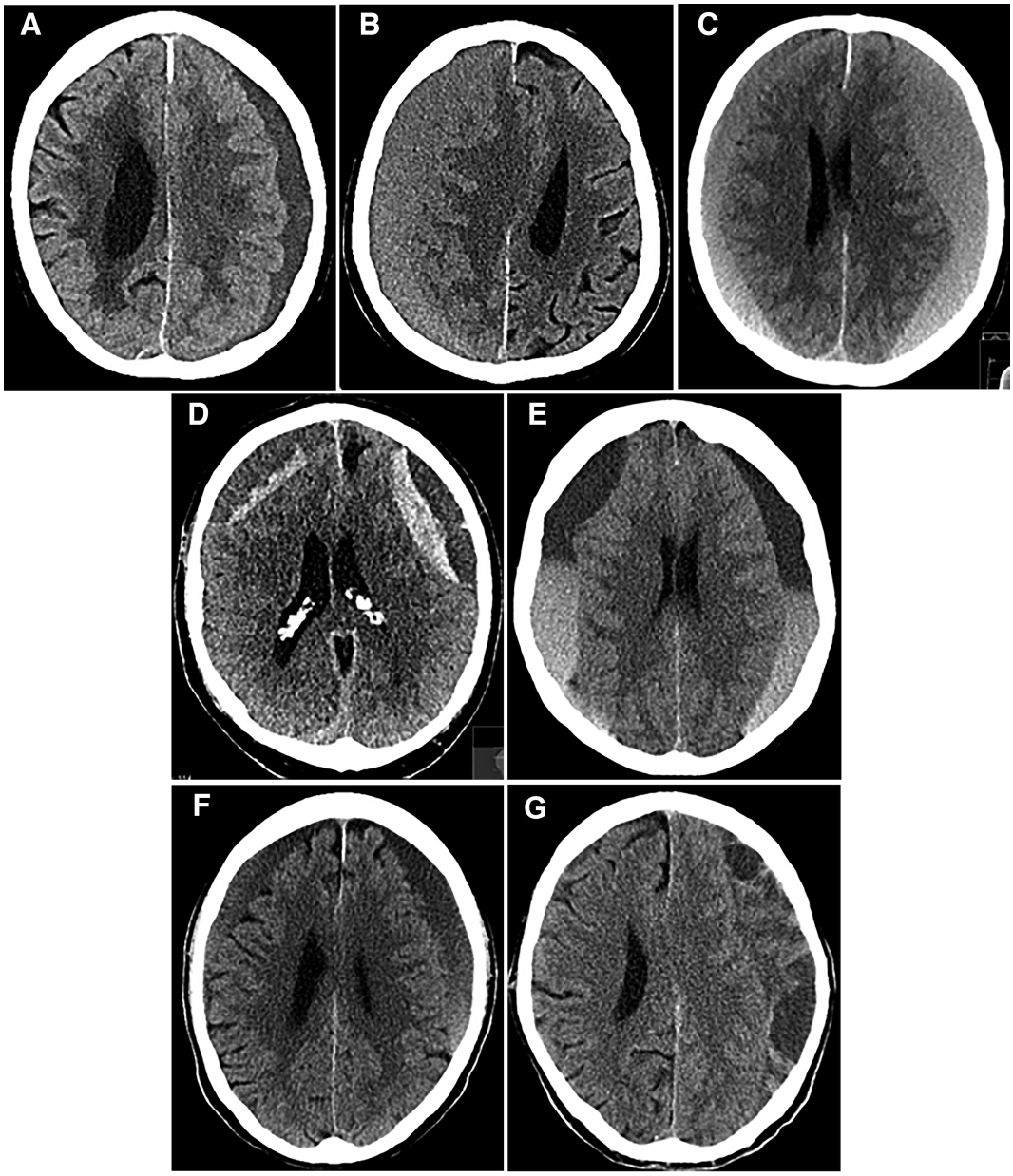


**FIGURE.** *CT imaging of representative patients with chronic subdural hematomas according to the classification described by Nakaguchi et al.*[7] **A**, *Hypodense subtype;* **B**, *isodense subtype;* **C**, *hyperdense subtype;* **D**, *laminar type;* **E**, *separated type;* **F**, *gradation subtype; and* **G**, *trabecular type (see the explanation in the text).*

95% (confidence interval, CI). Backward stepwise variable selection was performed using $P \leq .10$ as the criterion.

Furthermore, lasso regression was performed with 10-fold cross-validation, as implemented in the R package glmnet.[8] With increasing constraints on the sums of the absolute values of the coefficients, the solutions were shrunken versions of estimated coefficients, with some potential decreasing to the null value, and were eliminated from the model.[9]

Logistic regression was used to assess the association between the scoring system and RrR. The scoring system to predict CSDH RrR was then applied to the same set of patients in our database for internal validation.

A *P*-value < .05 was considered statistically significant and all tests were 2-tailed. Stata/SE 13.0 (StataCorp LP, College Station, Texas) was used for all statistical analyses.

## RESULTS

The overall rate of postoperative RrR for CSDH was 16% (17/107 patients) during the first 3 months, and 0 in the time period between 3 and 6 months after the initial surgery. In univariable analysis, none of the demographic, clinical, or surgical characteristics investigated or each of the most frequently associated concomitant diseases in these patients were associated with RrR (Table 1).

Univariable and multivariable regression analysis demonstrated that age over 80 years, male gender, history of brain infarction, and the $V_1$ subgroup greater than 130 mL were all significant predictors of increased $V_2$ (Table 2). Furthermore, univariable and multivariable regression analysis demonstrated that there was a great association between the subgroup of $V_1$ measuring more than 130 mL and the subgroups of $V_2$ ranging from 80 to 200 mL and above 200 mL ($P < .001$ and $P < .001$, respectively).

Upon univariable analysis, RrR was considerably higher in the CT scan imaging appearances of the subgroup of CSDH consisting of isodense or hyperdense subtypes and laminar or separated types, than in the CT scan imaging appearances of the subgroup of CSDH consisting of hypodense or gradation subtypes and trabecular types ($P < .001$; Table 1).

The selection of cut-off values for $V_1$ and $V_2$ was based on assessment of ROC curves to find the best predictive ability. Regarding the ROC curve of $V_1$, the area under the ROC curve was 0.71 (95% CI 0.57-0.84, $P = .003$). A cut-off of $V_1$ at 130 mL produced a sensitivity of 88% and a specificity of 41%. The probability of no RrR was estimated to be 95% if $V_1$ was below 130 mL, and 78% if $V_1$ was above 130 mL ($P = .017$; Table 1). Regarding the ROC curve of $V_2$, the area under the ROC curve was 0.76 (95% CI 0.64-0.87, $P < .001$). A cut-off for $V_2$ at 80 mL produced a sensitivity of 94% and a specificity of 40%. The probability of no RrR was estimated to be 97% if $V_2$ was below 80 mL, 81% if $V_2$ was 80 to 200 mL, and 50% if $V_2$ was above 200 mL ($P < .001$).

Therefore, age over 80 years, male gender, history of brain infarction, CT scan imaging appearances of the subgroup of CSDH consisting of isodense or hyperdense subtypes and laminar or separated types, the subgroup of $V_1$ measuring over 130 mL, the subgroup of $V_2$ ranging from 80 to 200 mL, and the subgroup of $V_2$ measuring over 200 mL were used for the development of a statistical prediction model to assess the prediction of RrR (Table 3).

Based on the results of this regression modeling, the CT scan imaging appearance of a subgroup CSDH consisting of isodense or hyperdense subtypes and laminar -or separated types, as well as $V_2$ measuring above 200 mL, were the strongest predictors of RrR; $V_1$ above 130 mL and $V_2$ ranging from 80 to 200 mL were moderate predictors. $V_1$ above 130 mL was not a significant predictor of RrR in the multivariable model and was not selected using the backward stepwise procedure. However, it was selected as a predictor in lasso regression. This statistical effect is likely due to the strong correlation between $V_1$ and $V_2$. In turn, these results of the regression modeling form the basis for the development of a prognostic CSDH grading system.

Thus, the prognostic CSDH grading system developed in this study consists of 3 components: CT scan imaging appearance based on density changes, $V_1$ and $V_2$. These components were divided into subcomponents, and each subcomponent was assigned specific points based on strength of association with postoperative RrR (Table 4). The subcomponent of $V_1$ measuring more than 130 mL was chosen because it represented a cut-off point for increased RrR. For higher $V_1$ (eg, >200 mL), an additional point was not assigned because, when assessed, this did not improve the accuracy of the prognostic CSDH grading system. The $V_2$ component was divided into 3 subcomponents to more precisely reflect the very strong influence of $V_2$ on RrR. The range of the prognostic CSDH grading system is 0 to 5.

The grading system was then applied to the same set of patients in our database to internally validate its predictive power, and the results are presented in Table 4. The estimated rate of postoperative RrR with 95% CI for groups of patients with different total score points on the grading system gave an internal validation measure. Thus, an increase in the prognostic CSDH grading score was associated with a progressive increase in RrR ($P < .001$ for trend; Table 4).

## DISCUSSION

Despite the fact that CSDH is a very common neurosurgical condition characterized by a high rate of postoperative RrR, there remains no widely adopted grading system for the prediction of RrR that can be used in clinical treatment and clinical research. It is likely that this lack of a prognostic grading system of RrR has contributed to great variability in enrolment characteristics for clinical CSDH research, to heterogeneity in neurosurgical treatment strategies and to great variability in surgical efficacy.

In a previously published article, Jack et al[10] presented a prognostic model for CSDH postoperative RrR surgery using a retrospective design and analysis of patients who underwent burr-hole surgery with drainage or craniotomy. In this 3-tier model, age with a cut-off of 80 years, a preoperative volume (determined by the ABC/2 method) with a cut-off of 160 mL, and the presence or absence of hematoma septation (corresponding to the trabecular type of hematoma according to the classification described by Nakaguchi et al[7]) were selected as components of the grading system.

We developed a new 3-component prognostic CSDH grading system for the prediction of RrR using a prospective design and analysis of patients who underwent single burr-hole surgery, irrigation of the cavity and closed-system drainage. Each component of the system, as well as the rationale for including

**TABLE 1. Relationship Between Demographic, Clinical, Surgical, Radiological Characteristics and Concomitant Disease and Postoperative Recurrence Requiring Reoperation in 107 Patients with Chronic Subdural Hematoma**

| Characteristics analyzed | Patients n (%) | Nonrecurrent n (%) | Recurrent n (%) | *P*-value |
|---|---|---|---|---|
| Gender | | | | |
| Male | 72 (67) | 58 (81) | 14 (19) | .14 |
| Female | 35 (33) | 32 (91) | 3 (9) | |
| Mean age ± SD (years) | | | | |
| Male | 71.4 ± 12.2 | 71.8 ± 11.6 | 69.9 ± 15.1 | .61 |
| Female | 73.6 ± 13.9 | 73.3 ± 14.5 | 76.7 ± 3.1 | .69 |
| Age categories (years) | | | | |
| ≤80 | 78 (73) | 66 (85) | 12 (15) | .81 |
| >80 | 29 (27) | 24 (83) | 5 (17) | |
| History of preceding head trauma event | | | | |
| Yes | 86 (80) | 72 (84) | 14 (16) | .82 |
| No | 21 (20) | 18 (86) | 3 (14) | |
| Mean interval from head injury to operation ± SD (days) | 53.5 ± 3 | 53.5 ± 30.5 | 53.1 ± 27.9 | .96 |
| History of antithrombotic (antiplatelets or anticoagulants) therapy | | | | |
| Yes | 51 (48) | 43 (84) | 8 (16) | .95 |
| No | 56 (52) | 47 (84) | 9 (16) | |
| Duration of antithrombotic therapy (years) | | | | |
| <1 | 8 (16) | 7 (88) | 1 (12) | .78 |
| ≥1 | 43 (84) | 36 (83.7) | 7 (16.3) | |
| Preoperative INR | | | | |
| ≤1.2 | 89 (83) | 76 (85) | 13 (15) | .42 |
| >1.2 | 18 (17) | 14 (78) | 4 (22) | |
| Preoperative GCS score[a] | | | | |
| 3-14 | 70 (65) | 60 (86) | 10 (14) | .53 |
| 15 | 37 (35) | 30 (81) | 7 (19) | |
| Combined hemiparesis or hemiplegia related to CSDH | | | | |
| Yes | 66 (62) | 58 (88) | 8 (12) | .17 |
| No | 41 (38) | 32 (78) | 9 (22) | |
| Speech deficiency related to CSDH | | | | |
| Yes | 38 (36) | 32 (84) | 6 (16) | .98 |
| No | 69 (64) | 58 (84) | 11 (16) | |
| Combined all neurological deficiencies related to CSDH[b] | | | | |
| Yes | 104 (97) | 88 (85) | 16 (15) | .40 |
| No | 3 (3) | 2 (67) | 1 (33) | |
| Mean drainage volume (mL) | 87 ± 75 | 76 ± 59 | 98 ± 90 | .19 |
| CT scan imaging appearance based on density changes | | | | |
| Hypodense or gradation subtypes and trabecular type | 61 (57) | 58 (95)) | 3 (5) | <.001[c] |
| Isodense or hyperdense subtypes and laminar or separated types | 46 (43) | 32 (70) | 14 (30) | |
| Mean preoperative volume in 2 subgroups | | | | |
| ≤130 mL | 40 (37) | 38 (95) | 2 (5) | .017[c] |
| >130 mL | 67 (63) | 52 (78) | 15 (22) | |
| Mean postoperative volume in 3 subgroups | | | | |
| <80 mL | 38 (36) | 37 (97) | 1 (3) | <.001[c] |
| 80-200 mL | 59 (55) | 48 (81) | 11 (19) | |
| >200 mL | 10 (9) | 5 (50) | 5 (50) | |
| Arterial hypertension | | | | |
| Yes | 47 (44) | 39 (83) | 8 (17) | .77 |
| No | 60 (56) | 51 (85) | 9 (15) | |
| Cardiac diseases | | | | |
| Yes | 40 (37) | 32 (80) | 8 (20) | .36 |
| No | 67 (63) | 58 (87) | 9 (13) | |
| Brain infarction | | | | |
| Yes | 24 (22) | 18 (75) | 6 (25) | .16 |
| No | 83 (78) | 72 (87) | 11 (13) | |

**TABLE 1** ***Continued.***

| Characteristics analyzed | Patients n (%) | Nonrecurrent n (%) | Recurrent n (%) | *P*-value |
|---|---|---|---|---|
| Diabetes mellitus | | | | |
| Yes | 16 (15) | 13 (81) | 3 (19) | .73 |
| No | 91 (85) | 77 (85) | 14 (15) | |
| Ethylisme | | | | |
| Yes | 12 (11) | 11 (92) | 1 (8) | .44 |
| No | 95 (89) | 79 (83) | 16 (17) | |
| Malignancy | | | | |
| Yes | 10 (9) | 8 (80) | 2 (20) | .70 |
| No | 97 (91) | 82 (85) | 15 (15) | |
| Dementia | | | | |
| Yes | 9 (8) | 7 (78) | 2 (22) | .58 |
| No | 98 (92) | 83 (85) | 15 (15) | |
| Liver dysfunction | | | | |
| Yes | 4 (4) | 4 (100) | 0 (0) | .37 |
| No | 103 (96) | 86 (84) | 17 (16) | |
| Combined all concomitant diseases | | | | |
| Yes | 88 (82) | 74 (84) | 14 (16) | .99 |
| No | 19 (18) | 16 (84) | 3 (16) | |

n, number of patients; SD, standard deviation; INR, international normalized ratio; GCS, Glasgow coma scale; CSDH, chronic subdural hematoma; CT, computerized tomography.
[a]The preoperative level of consciousness of patients was assessed using the Glasgow Coma Scale score.
[b]Included hemiparesis, hemiplegia, speech deficiency, incontinence, and gait disturbance.
[c]Significant.

**TABLE 2. Univariable and Multivariable Linear Regression Analyses of Characteristics Related to Postoperative Volume of Chronic Subdural Hematoma Cavity**

| | Univariable analysis | | Multivariable analysis | | Backward stepwise (included $P < .10$) | |
|---|---|---|---|---|---|---|
| Characteristics analyzed | B (95%CI) | *P*-value | B (95%CI) | *P*-value | B (95%CI) | *P*-value |
| If age > 80 years | 28.3 (2.7-53.9) | .03[a] | 24.5 (3.0-46.0) | .02[a] | 21.8 (0.4-43.2) | .04[a] |
| If male gender | 36.6 (12.8-60.3) | .003[a] | 22.7 (2.2-43.3) | .03[a] | 24.0 (3.3-44.7) | .02[a] |
| If history of brain infarction | 49.2 (23.0-75.4) | <.001[a] | 35.4 (12.8-58.1) | .002[a] | 35.7 (12.9-58.5) | .002[a] |
| If preoperative volume >130 mL | 62.0 (41.2-82.9) | <.001[a] | 48.6 (28.6-68.6) | <.001[a] | 46.5 (26.7-66.4) | <.001[a] |

B, coefficient from linear regression model; CI, confidence interval.
[a]Significant.

each component, deserves discussion. A CSDH with an isodense, hyperdense, laminar, or separated CT scan imaging appearance is considered to have a greater tendency toward rebleeding[7,11,12] and a high protein exudation rate,[13] which play recognized roles in the pathophysiology of CSDH. Hypodense and gradation subtypes of CSDH are considered to be earlier stages in the natural history of these lesions, characterized by a minor or moderate rebleeding tendency, and the trabecular type of CSDH is considered to be a resolution stage of these lesions, in which rebleeding from the hematoma membranes seems to abate.[7,12] In light of these considerations, it was not surprising when Stanišić et al[6] demonstrated that isodense and hyperdense subtypes, as well as laminar and separated types, carry a high risk for recurrence and can also be predictors of recurrence. In contrast, hypodense or gradation subtypes and trabecular type have low risks for recurrence. Thus, it was not unexpected to find in this study that the isodense or hyperdense subtypes and laminar or separated types of lesions were strong predictors of RrR in the logistic and lasso regression analyses (Table 3). Therefore, these density appearance subgroups were subsequently chosen as subcomponents of the prognostic CSDH grading system.

It has long been suggested that CSDH development and increased lesion size are attributed to brain atrophy associated with aging, which may provide the lesion with a potential space to

**TABLE 3. Univariable and Multivariable Logistic Regression Analyses of Characteristics Related to Postoperative Recurrence Requiring Reoperation of Chronic Subdural Hematoma**

| | Univariable analysis | | Multivariable analysis | | Backward stepwise (included $P < .10$) | | Lasso regression coefficient |
|---|---|---|---|---|---|---|---|
| **Characteristics analyzed** | **OR (95% CI)** | ***P*-value** | **OR (95% CI)** | ***P*-value** | **OR (95% CI)** | ***P*-value** | |
| If age > 80 years | 1.1 (0.4-3.6) | .81 | 1.3 (0.3-5.9) | .69 | | | |
| If male gender | 2.6 (0.7-9.6) | .16 | 1.3 (0.3-6.7) | .72 | | | |
| If history of brain infarction | 2.2 (0.7-6.7) | .17 | 1.3 (0.3-5.4) | .67 | | | |
| If CSDH isodense or hyperdense subtypes and laminar or separated types | 8.5 (2.7-31.6), | .002[a] | 7.9 (1.8-34.8) | .006[a] | 7.2 (1.8-28.8) | .005[a] | 1.39 |
| If preoperative volume >130 mL | 5.5 (1.2-25.4) | .03[a] | 1.7 (0.3-10.4) | .58 | | | 0.46 |
| If postoperative volume 80- 200 mL | 8.5 (1.0-68.7) | .04[a] | 6.5 (0.7-193.5) | .11 | 9.1 (1.1-76.5) | .04[a] | 0.49 |
| If postoperative volume >200 mL | 37 (3.6-384.6) | .003[a] | 11.7 (0.7-193.5) | .08 | 23.2 (2.1-256.6) | .01[a] | 1.30 |

OR, odds ratio; CI, confidence interval; CSDH, chronic subdural hematoma.
[a]Significant.

**TABLE 4. Oslo Chronic Subdural Hematoma Grading System for Prediction of Postoperative Recurrence Requiring Reoperation**

| **Components of the prognostic grading system** | **Score points** |
|---|---|
| CT scan imaging appearance based on density changes | |
| Isodense or hyperdense subtypes and Laminar or separated types | 2 |
| Hypodense or gradation subtypes and trabecular type | 0 |
| Preoperative volume (mL) | |
| >130 | 1 |
| ≤130 | 0 |
| Postoperative residual cavity volume (mL) | |
| >200 | 2 |
| 80-200 | 1 |
| <80 | 0 |
| Total score | 0-5 |

**Interpretation:**
**The rate of 6-month postoperative recurrence requiring reoperation increases as the total score increases.**

| **Total score points** | **Nonrecurrence n** | **Recurrence requiring reoperation n** | **Rate of recurrence requiring reoperation (with 95% CI)** | ***P*-value** |
|---|---|---|---|---|
| 0 | 18 | 0 | 0% (0%-18%) | <.001[a] |
| 1-2 | 48 | 3 | 6% (1%-16%) | |
| 3-4 | 21 | 9 | 30% (15%-49%) | |
| 5 | 3 | 5 | 63% (25%-92%) | |

N, number of patients; CI, confidence interval; CT, computerized tomography.
[a]Significant.

grow. However, this general opinion cannot be absolutely proven; computer-assisted quantification of brain atrophy derived from CT imaging in patients with CSDH on initial presentation is not possible due to mass effect of the lesion. A previously suggested method for the assessment of brain atrophy in patients with CSDH, based on a 3-grade system,[10,14] is a more subjective measure. Only recently, Yang et al,[15] demonstrated that brain atrophy was associated with the development of CSDH at all ages by using computer-assisted quantitative analysis of subsequent CT scans from patients who were previously diagnosed with CSDH. It has also long been suggested that brain atrophy may lead to inappropriate brain re-expansion postoperatively, thereby creating the potential for reaccumulation of the lesion. However, it was only recently that this general opinion could be confirmed by computer-assisted quantitative analysis of serial CT scans from patients diagnosed with CSDH.[16] Therefore, it was not surprising when recent studies, through more sophisticated quantitative volumetric analyses of CT scans in patients with

CSDH, demonstrated that a large $V_1$ and large $V_2$, regardless of whether the lesions were unilateral or bilateral, may be predictors of recurrence.[6,17]

In light of these considerations, it was not an unexpected finding in this study that there was an association between the subgroup of $V_1$ measuring more than 130 mL and the subgroups of $V_2$ ranging from 80 to 200 mL and above 200 mL. Furthermore, these 3 volumetric variables were predictors of RrR in the model (Table 3). Therefore, these 3 volumetric variables were subsequently selected as components of the prognostic system. The results of the subgroups of $V_2$ ranging from 80 to 200 mL as well as $V_2$ above 200 mL, which may indicate a lower tendency and ability of the brain to re-expand postoperatively, may have practical implications for patient treatment. Namely, this suggests that the time duration of drainage as well as the optimization of fluid and electrolyte balance should be considered more properly, as noted earlier.[4,18]

Age over 80 years, male gender, and history of brain infarction were not significant independent predictors of RrR. They were also excluded from the multivariable logistic regression model based on variable selection using backward stepwise selection and lasso regression analysis (Table 3). These variables were consequently excluded as components of the prognostic CSDH grading system. Additional factors considered in the study, such as neurological symptoms and signs, level of consciousness, use of antithrombotic therapy, functionality of closed-system drainage, and medical comorbidities, which will always play an important role in patient clinical care, did not improve the accuracy of the prognostic CSDH grading system and are not represented there.

The prognostic CSDH grading system has been simplified into a reliable clinical grading scale, which may serve several valuable purposes. Thus, standardization of patient assessments using this tool may provide initial individual prognostic information regarding recurrence and reoperation in patients treated with this surgical strategy, which is important to assess surgery benefits and risks and to provide patients and families with such information. Furthermore, use of this grading system can standardize clinical care of patients, improve consistency in communication among neurosurgeons, improve enrolment criteria for clinical research, provide reliable criteria for assessing treatment strategies efficacy and comparisons of treatment efficacy between clinical studies, and assess the efficacies of known and new treatment strategies. Therefore, the grading system can be used as part of a standardized clinical assessment of all patients with CSDH, which likely will provide more consistency in clinical neurosurgical care and clinical research for this lesion just as similar assessment grading systems have provided consistency in traumatic brain injury, aneurysmal SAH, ischemic stroke, arteriovenous malformation, and intracerebral hemorrhage. This, in turn, may be a significant step toward developing a most optimal treatment and new treatments for CSDH.

However, the proposed grading system is not necessarily a perfectly accurate risk stratification tool for screening patients with CSDH and is likely to evolve as research identifies more contributing factors.

### Limitations

The main disadvantage of this single-center trial is the relatively small sample in the initial analysis, which may limit the ability to demonstrate statistical significance. Therefore, an external validation of the proposed CSDH grading system with de novo data set is wanted to confirm its clinical utility and applicability.

## CONCLUSION

There is no widely adopted grading system for the prediction of postoperative RrR in patients with CSDH. We developed a new prognostic CSDH grading system for this purpose, which consisted of 3 components: CT scan imaging appearance based on density changes, $V_1$ and $V_2$. These components were divided into subcomponents, and each subcomponent was assigned specific points based on the strength of association with postoperative recurrence requiring repeat surgery. Combining subcomponents in the prognostic grading system is a powerful and applicable tool for postoperative RrR risk stratification in patients with CSDH. Large-scale and prospective application of the proposed grading system would strengthen its clinical utility and universal applicability in practice.

### Disclosures

In the first previous report of this dataset of patients, it was demonstrated from CT imaging that the pre- and postoperative maximum thickness of CSDH on the first postoperative day after removal of the drain does not offer reasonable approximations of the pre- and postoperative lesion size when compared with results from the computer-assisted quantification method in the unilateral subgroup, bilateral subgroup, or overall.[5] The approach in the second previous report of this dataset of patients was to characterize the relationship between the recurrence of CSDH after treatment with single burr-hole evacuation, irrigation and closed-system drainage technique, and the variety of findings from CT imaging assessed quantitatively or qualitatively.[6] The authors have no personal, financial, or institutional interest in any of the drugs, materials, or devices described in this article.

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