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Predictor of the Postoperative Swelling After Craniotomy for Spontaneous Intracerebral Hemorrhage: Sphericity Index as a Novel Parameter

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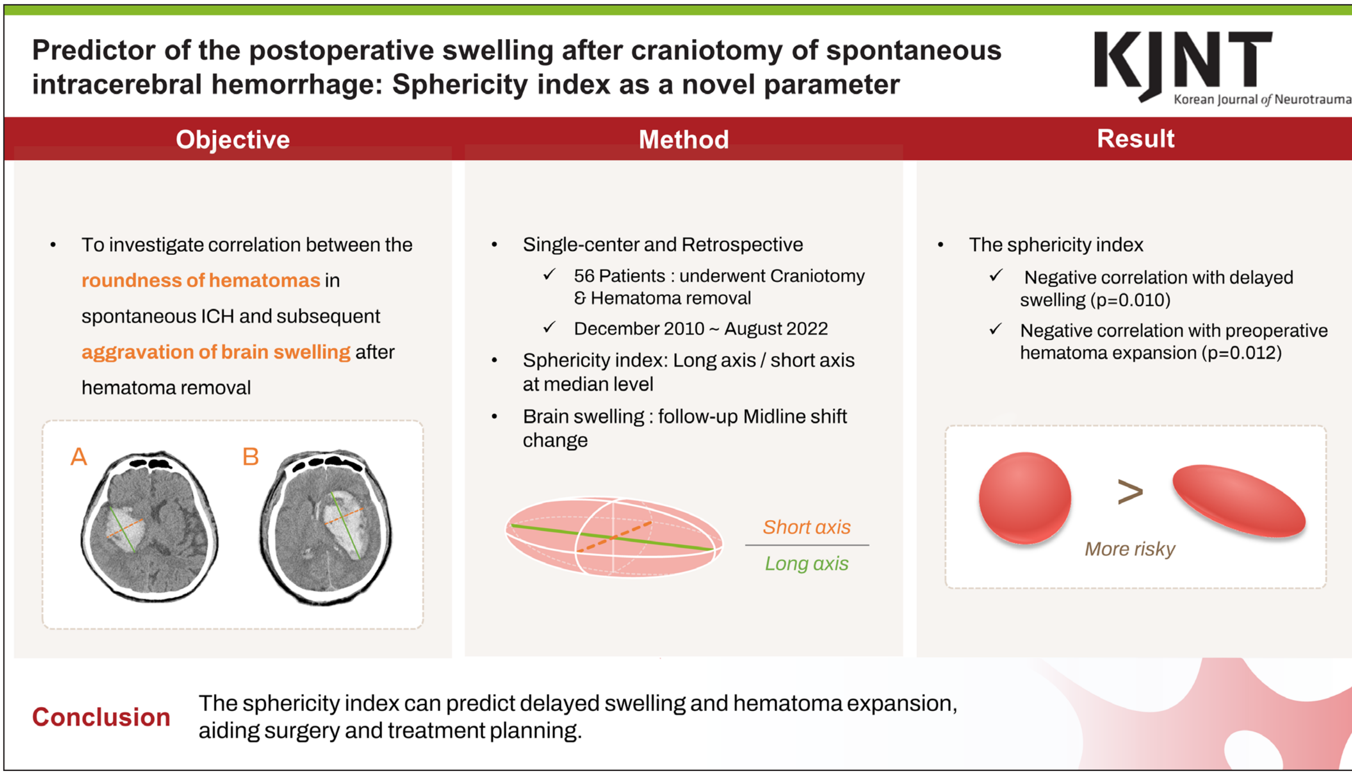
ABSTRACT

Objective: Spontaneous intracerebral hemorrhage is a serious type of stroke with high mortality and disability rates. Surgical treatment options vary; however, predicting edema aggravation is crucial when choosing the optimal approach. We propose using the sphericity index, a measure of roundness, to predict the aggravation of edema and guide surgical decisions.
Methods: We analyzed 56 cases of craniotomy and hematoma evacuation to investigate the correlation between the sphericity index and patient outcomes, including the need for salvage decompressive craniectomy (DC).
Results: The patients included 35 (62.5%) men and 21 (37.5%) women, with a median age of 62.5 years. The basal ganglia was the most common location of hemorrhage (50.0%). The mean hematoma volume was 86.3 cc, with 10 (17.9%) instances of hematoma expansion. Cerebral herniation was observed in 44 (78.6%) patients, intraventricular hemorrhage in 34 (60.7%), and spot signs in 9 (16.1%). Salvage DC was performed in 13 (23.6%) patients to relieve intracranial pressure. The median follow-up duration was 6 months, with a mortality rate of 12.5%. The sphericity index was significantly correlated with delayed swelling and hematoma expansion but not salvage DC.
Conclusions: The sphericity index is a promising predictor of delayed swelling and hematoma expansion that may aid in the development of surgical guidelines and medication strategies. Further large-scale studies are required to explore these aspects and establish comprehensive guidelines.

Keywords: Intracranial hemorrhages; Craniotomy; Decompressive craniectomy; Brain edema

GRAPHICAL ABSTRACT



Conflict of Interest
The authors have no financial conflicts of interest.

INTRODUCTION

Spontaneous intracerebral hemorrhage (S-ICH) is the second most common type of stroke, occurring in over one million patients annually.[7] The mortality rate within 1 month is up to 40%, twice as high as that of ischemic stroke.[2,12,31] Further, survivors often develop severe disabilities.[7] Since no standardized surgical technique exists for S-ICH, various options are considered for surgical treatment.[21,33] These options include minimally invasive procedures such as stereotaxic hematoma aspiration or endoscopic clot evacuation, and open surgeries such as decompressive craniectomy (DC) or craniotomy with hematoma evacuation. Among these options, open surgery allows for faster hematoma removal and provides an advantage in achieving meticulous hemostasis of the walls of the hematoma cavity.[15] The choice between craniectomy and craniotomy depends on factors such as the patient's Glasgow Coma Scale (GCS) score at the time of surgery, preoperative midline shift (MLS), and intraoperative brain swelling. In some cases, after craniotomy and hematoma evacuation, the intraoperative view shows minimal brain swelling, leading to the closure of the bone flap. However, significant aggravation of the edema may develop in the following days, necessitating an additional DC. In such cases, multiple surgeries under general anesthesia can significantly impact the patient's general condition, and delay in achieving adequate decompression may adversely affect the patient's prognosis. Compared with craniotomy and hematoma evacuation, DC has a larger surgical area and involves more bleeding,[16] resulting in relatively inferior functional outcomes.[22] Moreover, subsequent cranioplasty surgery, which carries a high complication rate of 30%, may be necessary.[13] Due to these factors, performing DC as an initial treatment for all patients requiring surgery may be excessive and can be accompanied by several drawbacks.

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Therefore, if delayed edema aggravation can be predicted in advance, based on intraoperative findings and through preoperative imaging, clinicians may determine whether to proceed with DC or craniotomy with hematoma evacuation.

In this study, we investigated the correlation between the Roundness of Hematomas in S-ICH and subsequent aggravation of patient's condition, and its association with the need for salvage DC.

MATERIALS AND METHODS

Between December 2010 and August 2022, 173 patients who underwent surgery for spontaneous supratentorial intracerebral hemorrhage were included in the study. At our institution, neurosurgeons share a consensus regarding the method of ICH surgery. The surgical method was selected considering the initial neurological status of each patient, mass effect, MLS on brain imaging, and intraoperative findings, including brain swelling. Small hematomas with minimal neurological deficits are treated conservatively, whereas small- to medium-sized hematomas with definitive neurological deficits are treated with stereotactic hematoma aspiration. Medium- to large-volume hematomas were managed by using a transcranial approach. Craniotomy or DC was chosen based on intraoperative surgical findings, including brain swelling. A total of 173 patients were included in this study, of which 68, 57, and 48 patients underwent DC, craniotomy, and stereotactic aspiration, respectively.

We analyzed 57 patients who underwent craniotomy and hematoma removal after excluding those who initially underwent DC or stereotactic hematoma aspiration. One patient with an indistinguishable hematoma border was excluded, leaving 56 patients for the study.

Based on the initial computed tomography (CT) scans of the patients, the location of the hematoma was classified as frontal, parietal, temporal, or occipital. The hematoma was classified as a lobar ICH if it did not invade deep structures. Hematomas extending throughout the basal ganglia and thalamus were defined as deep-seated ICH. Hematomas spanning the lobar and deep structures or localized solely in the thalamus or basal ganglia were defined separately.

Hematoma volume was calculated using the ABC/2 method. The product of the 2 axes on the same CT slice was multiplied by the number of slice cuts and the slice interval. This value was then divided by 2 to obtain the hematoma volume.[1,39]

The sphericity index assesses the roundness of a chamber or cavity and has been employed to predict postoperative prognosis in patients with atrial fibrillation.[4] In the early stages of a disease, when an organ needs to adapt to high pressure rapidly, a spherical shape optimizes the surface area to volume ratio, which is considered ideal.[30] It allows the organ to cope with high pressure and hematoma expansion with minimal stress. The sphericity index was measured using a simple method that involved dividing the length of the longest axis of the hematoma on the median level slice of the axial CT by the perpendicular axis length (long axis/short axis) (FIGURE 1).[11,20] Four neurosurgeons participated in the measurement of the sphericity index. After independent measurements, we calculated the average value of the sphericity index, ensuring a comprehensive and dependable evaluation.

The degree of delayed postoperative swelling aggravation was estimated by comparing MLS values on postoperative CT scans with those on follow-up (FU) CT scans. The MLS was

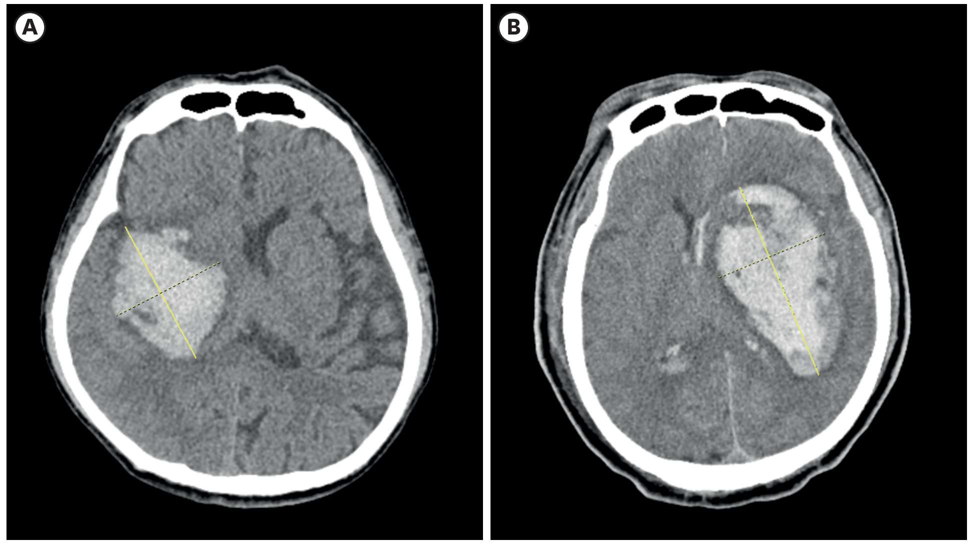

FIGURE 1. Sphericity index on CT. The sphericity index represents the ratio of the longest diameter to the diameter perpendicular to it on a CT scan. (A) A rounded hematoma, exhibiting a sphericity index close to 1. (B) Conversely, where an elliptical hematoma is present, a relatively higher sphericity index value is observed. Solid line, longest diameter; dotted line, perpendicular diameter.
CT: computed tomography.

measured based on the distance of the septum pellucidum shift to the level at which the foramen of Monro was visible. If the MLS on the initial CT scan was 5mm or more, it was defined as herniation-positive. Hematoma expansion was defined as a change in volume between the initial and preoperative CT scans. The presence of a spot sign, indicating extravasation of the contrast medium on contrast-enhanced CT or CT angiography, was defined as positive. If these tests were not performed, the spot sign was classified as unknown.

Patient data, including age, sex, history of hypertension and diabetes, use of anticoagulants and antiplatelet agents, admission-to-surgery time, length of hospital stay, FU observation period, initial GCS score, modified Rankin Scale (mRS) score at discharge and last FU, were extracted from the medical records.

Statistical analyses were performed using the SPSS version 27.0.0 (IBM Corp., Armonk, NY, USA). Statistical significance was set at $p<0.05$.

Ethical standards

This study, designed as a retrospective cohort study, was conducted at Korea University Guro Hospital after obtaining approval from the Institutional Review Board (approval No. K2023-2215-001). This retrospective study was approved by the ethics committee and has therefore been performed in accordance with the ethical standards of the 1964 Declaration of Helsinki and its later amendments.

RESULTS

Patient demographics

In total, 56 individuals were identified, of which 35 (62.5%) were men and 21 (37.5%) were women. The median age was 62.5 years, with a range of 27–84 years.

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In total, 20 patients (35.7%) had hypertension, and 12 (21.4%) had diabetes. Twelve patients (21.4%) were taking antiplatelet medications, while 4 (7.1%) were taking anticoagulants.

During the initial examination, 25 patients (44.6%) had a mild GCS score of 13–15, 12 (21.5%) had a moderate GCS score of 9–12, and 19 (33.9%) had a severe GCS score of 3–8 (**TABLE 1**). The basal ganglia was the most common location of the hemorrhage, and 28 individuals (50.0%) were affected. Subsequently, 14 individuals (25.0%) had lobar hemorrhages, whereas 11 (19.6%) had hemorrhages spanning the deep brain structures and lobes.

The mean median hemorrhage volume was calculated to be 86.3 cc, ranging from 25.2 to 226.2 mL. Among these patients, 10 (17.9%) had hematoma expansions accompanied by hemorrhage.

Herniation was observed in 44 patients (78.6%), and 34 (60.7%) had intraventricular hemorrhage (IVH). Additionally, 9 patients (16.1%) showed presence of spot signs (**TABLE 1**).

Treatment

All patients underwent craniotomy and hematoma evacuation surgery, and among them, one individual (1.8%) required additional hematoma evacuation surgery due to hemorrhage recurrence. Thirteen patients (23.6%) underwent additional DC because of worsening neurological symptoms and deteriorating radiological findings.

The median time from admission to surgery was 5 hours (range 1–78 hours). Among these patients, 38 (67.9%) underwent surgery within 8 hours, and 9 (83.9%) underwent surgery within 24 hours. Delayed surgery beyond 24 hours was associated with the aggravation of neurologic symptoms or hematoma expansion (**TABLE 1**).

Outcome

The median FU duration was 6 months. During the FU period, 7 (12.5%) patients died, all of whom died during hospitalization. Among these deaths, 5 were attributed to worsening intracranial lesions, one to pneumonia, and one was caused by catheter-related bloodstream infection.

At discharge, the mean mRS score was 4.84. At the last FU, the mean mRS score was 4.39 (**TABLE 1**).

The mean sphericity index value was 1.52, ranging from 1.02 to 2.4 (**TABLE 2**). To assess the severity of postoperative swelling aggravation, MLS values were measured on postoperative CT scans and FU images. The average MLS on postoperative CT was measured as 6.36 mm (**TABLE 2**). The FU images were primarily based on images taken within the first 2 weeks after surgery. For cases where additional surgery was performed due to deteriorating neurology, the MLS was measured based on the image obtained immediately before the surgery. On average, the FU images obtained on the 6th day showed a MLS of 7.63 mm (**TABLE 2**).

The extent of delayed postoperative swelling aggravation was indirectly measured through the differences in the MLS value between the FU image and postoperative CT. Correlation coefficient analysis between the sphericity index and postoperative MLS change showed a significant correlation (p=0.01) (**TABLE 3**). A simple linear regression analysis showed a negative correlation between the sphericity index and MLS change (B=−4.328; β=−0.340; t=−2.657; p=0.01) (**TABLE 4**, **FIGURE 2**).

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TABLE 1. Characteristics of enrolled patients who have undergone craniotomy and hematoma removal surgery for spontaneous intracerebral hemorrhage

Characteristics	Value
Sex (%)	
Male	35 (62.5)
Female	21 (37.5)
Age (years)	
Mean ± SD	63.4±13.1
Median (range)	62.5 (27–84)
Medical history (%)	
HTN	20 (35.7)
DM	12 (21.4)
Medication (%)	
Antiplatelet	12 (21.4)
Anticoagulant	4 (7.1)
GCS score in arrival (%)	
13–15	25 (44.6)
9–12	12 (21.5)
3–8	19 (33.9)
Hemorrhage volume (mL)	
Mean ± SD	93.4±44.9
Median (range)	86.3 (25.2–226.2)
Herniation (%)	
Yes	44 (78.6)
No	12 (21.4)
Hematoma expansion (%)	
Yes	10 (17.9)
No	46 (82.1)
Presence of IVH (%)	
Yes	34 (60.7)
No	22 (39.3)
Spot sign (%)	
Yes	9 (16.1)
No	34 (60.7)
Unknown	13 (23.2)
Hematoma location (%)	
Lobar	14 (25.0)
BG	28 (50.0)
Thalamus	0 (0)
BG + Thalamus	3 (5.4)
Deep + Lobar	11 (19.6)
Surgical treatment (%)	
Craniotomy & Hematoma removal only	42 (76.4)
Craniotomy + Craniotomy	1 (1.8)
Craniotomy + Salvage craniectomy	13 (23.6)
Admission to surgery (hours)	
Mean ± SD	12.61±16.95
Median (range)	5.00 (1–78)
Hospital stay period (days)	
Median (range)	34.0 (7–590)
Discharge mRS (mean ± SD)	4.84±0.73
Last follow-up mRS (mean ± SD)	4.39±1.33
Death	7 (12.5)
Follow-up period (months)	
Median (range)	6.0 (0–142)

Values are presented as number (%).
SD: standard deviation, HTN: hypertension, DM: diabetes mellitus, GCS: Glasgow Coma Scale, IVH: intraventricular hemorrhage, BG: basal ganglia.

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TABLE 2. Sphericity index and midline shift change

Characteristics	Value
Sphericity index	
Mean ± SD	1.520±0.327
Median (range)	1.510 (1.020–2.400)
Postoperative midline shift (mm)	
Mean ± SD	6.360±3.312
Follow-up CT midline shift (mm)	
Mean ± SD	7.630±5.350
Postoperative follow-up CT period (days)	
Mean ± SD	6.000±2.676
Median (range)	7.000 (1–14)
Postoperative midline shift change (mm)	
Mean ± SD	1.270±4.160

SD: standard deviation, CT: computed tomography.

TABLE 3. Correlation coefficient analysis between 2 factors

Characteristics	Hematoma expansion	Salvage DC	Postop MLS change
Sphericity index			
Correlation coefficient	−0.265	−0.134	−0.340
p-value	0.048*	0.323	0.010*
Number	56	56	56
Hematoma expansion			
Correlation coefficient		0.296	0.335
p-value		0.027*	0.012*
Number		56	56
Salvage DC			
Correlation coefficient			0.754
p-value			<0.001**
Number			56

We employed the following types of correlation analyses based on the types of variables. (1) Point biserial correlation: sphericity index and hematoma expansion, sphericity index and salvage DC, postop MLS change and hematoma expansion, postop MLS change and salvage DC. (2) Pearson correlation: postop MLS change and sphericity index. (3) Phi coefficient: hematoma expansion and salvage DC. Duplicated or identical variable correlations are highlighted in gray.
DC: decompressive craniectomy, MLS: midline shift.

TABLE 4. Simple and multiple linear regression analysis of predictors of the postoperative midline shift change

Predictors	B	β	95% CI of B	*p*-value
Simple				
Sphericity index	−4.328	−0.340	−7.594, −1.062	0.010*
HTN	−0.393	−0.046	−2.738, 1.952	0.738
Antiplatelet	−0.458	−0.046	−3.196, 2.281	0.739
Anticoagulant	0.358	0.022	−4.008, 4.724	0.870
Hematoma expansion	3.606	0.335	0.839, 6.373	0.012*
IVH presence	−0.719	−0.085	−3.014, 1.575	0.532
Spot sign	−1.270	−0.257	−2.570, 0.031	0.055
Hematoma volume	−0.002	−0.022	−0.027, 0.023	0.875
Multiple				
Sphericity index	−2.596	−0.204	−6.258, 1.067	0.161
HTN	0.834	0.097	−1.585, 3.253	0.492
Antiplatelet	−0.450	−0.045	−3.338, 2.438	0.755
Anticoagulant	−0.404	−0.025	−4.771, 3.963	0.853
Hematoma expansion	3.538	0.329	0.251, 6.825	0.035*
IVH presence	0.429	0.051	−2.244, 3.102	0.748
Spot sign	−1.253	−0.254	−2.704, 0.199	0.089
Hematoma volume	−0.008	−0.083	−0.035, 0.019	0.570

B: unstandardized coefficients, β: standardized coefficients, CI: confidence interval, HTN: hypertension, IVH: intraventricular hemorrhage.
**p*-value <0.05.

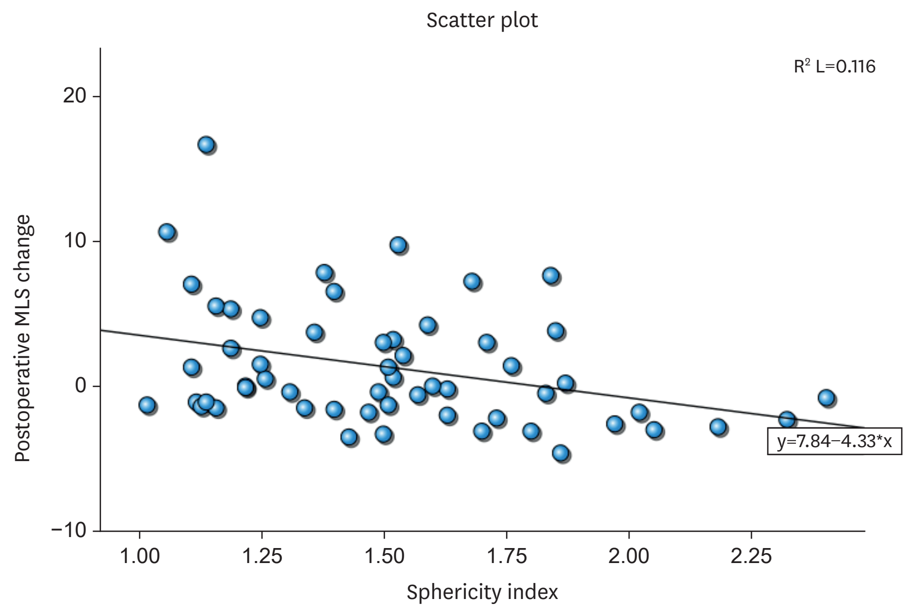

FIGURE 2. The scatter plot, along with the regression line, demonstrates a negative correlation between edema aggravation and the sphericity index.

Moreover, the sphericity index significantly correlated hematoma expansion in the preoperative image. In the correlation coefficient analysis, the *p*-value was 0.048 (**TABLE 3**), and the receiver operating characteristic (ROC) curve analysis exhibited an area under the ROC curve of 0.709 with a *p*-value of 0.040 (**FIGURE 3**). Utilizing Youden's J index to determine the optimal cut-off point, a sphericity index lower than 1.495 was established to indicate the presence of hematoma expansion, with a sensitivity of 0.80 and a specificity of 0.609 (**FIGURE 4**).

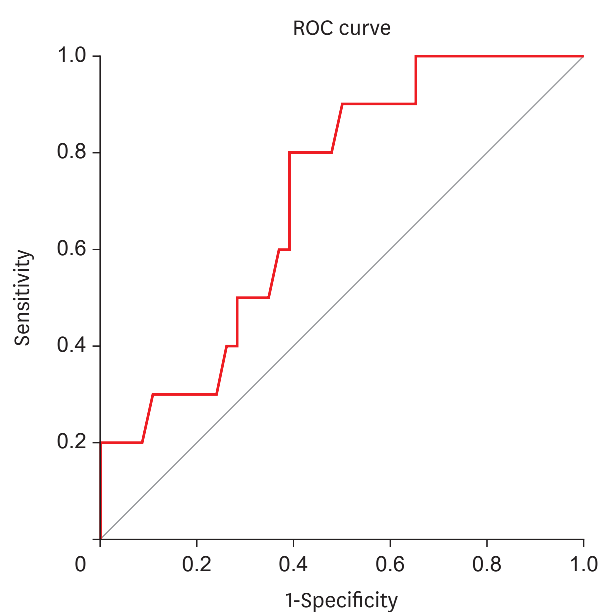

FIGURE 3. The ROC curve of the sphericity index was used for predicting hematoma expansion. The area under the curve for the sphericity index was 0.709.
ROC: receiver operating characteristic.

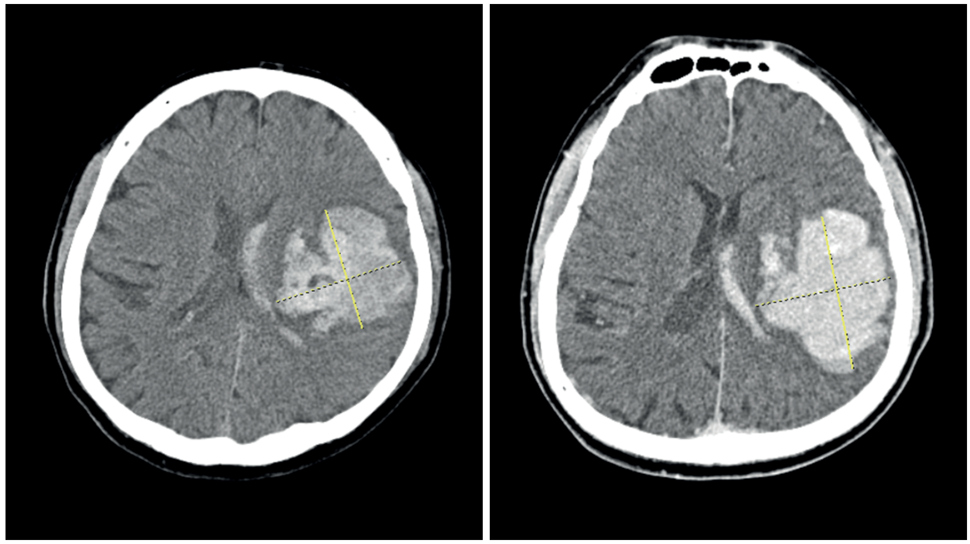

FIGURE 4. A patient exhibiting a low sphericity index (1.04) on the initial CT scan displayed hematoma expansion in the preoperative follow-up CT scan; the sphericity index still remaining low (1.18).
CT: computed tomography.

Furthermore, in the correlation analysis, the relationship between MLS change and hematoma expansion demonstrated a significant correlation (p=0.012) (TABLE 3).

In the linear regression analysis, both the sphericity index and hematoma expansion were identified as statistically significant predictors of postoperative MLS change (TABLE 4). However, the sphericity index showed significance only in simple linear regression analysis (p=0.010), while hematoma expansion remained significant in both simple (p=0.012) and multiple linear regression analysis (p=0.035).

Salvage DC

Salvage DC was significantly correlated with hematoma expansion in the preoperative image. However, it did not exhibit significant correlation with the sphericity index. In the correlation coefficient analysis, hematoma expansion was significantly associated with salvage DC (p=0.027) (TABLE 3). In the logistic regression analysis examining the predictors of salvage DC, hematoma expansion was identified as a significant risk factor (TABLE 5). The findings revealed that the likelihood of undergoing salvage DC increased by approximately 4.75 times when hematoma expansion was present, compared with cases in which it was not observed.

TABLE 5. Logistic regression analysis of predictors of the salvage decompressive craniectomy

Predictors	B	OR	95% CI of B	*p*-value
Sphericity index	−1.063	0.345	0.043, 2.800	0.319
HTN	−0.288	0.750	0.198, 2.836	0.672
Antiplatelet	−1.417	0.242	0.028, 2.085	0.197
Anticoagulant	0.105	1.111	0.106, 11.689	0.930
Hematoma expansion	1.558	4.750	1.108, 20.357	0.036*
IVH presence	−0.778	0.459	0.131, 1.615	0.225
Spot sign	0.377	1.458	0.257, 8.276	0.670
Hematoma volume	0.003	1.003	0.990, 1.017	0.647

B: unstandardized coefficients; OR: odds ratio, CI: confidence interval, HTN: hypertension, IVH: intraventricular hemorrhage.
*p-value <0.05.

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Nevertheless, the presence of salvage DC did not demonstrate a significant correlation with the sphericity index, as indicated by both correlation analysis (p=0.323) and logistic regression analysis (p=0.319).

DISCUSSION

The main finding of this study is that the sphericity index can be used as a significant factor in predicting the worsening of brain swelling after surgery and the potential expansion of hematomas. The observed significant correlation between the sphericity index, hematoma expansion, and MLS change can be attributed to specific underlying mechanisms. S-ICH is commonly occurred from microaneurysms due to long-lasting hypertension. It usually occurred in deep nuclei such as putamen or thalamus. These regions allow the hemorrhage to expand along spaces adjacent to white matter tracts. We hypothesized that more round-shaped hematoma harbors higher internal pressure than elongated one. Thus, rounded hematoma, characterized by higher internal pressures, might increase risk of re-bleeding from culprit vessels and contribute to a heightened secondary insult associated with ICH.

Although both conservative and surgical treatments have been continuously evolving for the management of S-ICH, the 2 largest randomized trials (STITCH and STITCH II) suggest that early surgical treatment for supratentorial ICH does not provide significant benefits in terms of functional outcome and mortality when compared with conservative treatment.[18,27,28] Surgical reduction of hematoma volume can immediately and effectively reduce the damage to nervous tissue by reducing noxious chemicals caused by the hematoma and decrease local ischemic injury by reducing perilesional pressure.[28,33] For these reasons, many institutions continue to perform surgical treatment, and our institution also actively performs surgery, considering the amount of hematoma, extent of swelling, and severity of neurological symptoms. However, early surgical treatment may not provide significant benefits because of the difficulty in predicting the severity of the disease course, leading to the establishment of appropriate indications. Several studies have attempted to predict the worsening of early neurological symptoms or 30-day mortality caused by ICH using factors such as GCS score, age, presence of IVH, ICH volume, and hematoma expansion.[17,23,34] However, these findings are still insufficient for predicting radiological and neurological deterioration.

Perilesional edema is a significant quantifiable marker of secondary brain injury. It rapidly develops within a few hours due to clot retraction and cytotoxic edema, followed by destruction of the blood-brain barrier through inflammatory responses, leading to the induction of vasogenic edema over a span of 2–3 days.[6,36] This vasogenic edema can worsen over a 2-week and typically resolves within 1 month. Furthermore, the progression of perilesional edema over 72 hours is particularly associated with the initial volume and surface area of the ICH.[3,6,38] Several studies have shown that worsening of perilesional edema is significantly associated with poor outcomes and 90-day mortality in ICH.[14,29,37,40] However, apart from hematoma volume and surface area, no known factors currently predict the worsening of perilesional edema radiologically. The locations of ICH, IVH, and hematoma expansion were not significantly associated with perilesional edema aggravation.[35,40]

Hematoma expansion is also closely related to poor outcomes.[8] It occurs in approximately one-third of patients with ICH and significantly predicts of early neurologic deterioration and subsequent poor long-term clinical outcomes.[5] The Spot Sign Score is a good

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independent predictive factor with a high probability of predicting hematoma expansion and demonstrates high inter-observer agreement.[9,19] This score is significantly associated with in-hospital mortality and a poor outcome at 90 days for patients.[10] However, performing CT angiography or contrast-enhanced CT may not be feasible due to the patient's or the hospital's circumstances. In such cases, the prediction of hematoma expansion using various other markers on non-contrast CT has been explored, such as the Blend sign,[24,41] black hole sign,[25] satellite sign,[32] and island sign.[26]

Factors associated with delayed aggravation of perilesional edema include the initial hematoma volume and surface area. Additionally, the spot sign on CT angiography is a well-established factor related to hematoma expansion, and various signs on non-contrast CT scans have been consistently studied, as mentioned above. However, determining the appropriate surgical approach for DC and craniotomy remains challenge in clinical practice.

The sphericity index can serve as an additional marker, along with baseline hematoma volume and surface area, for predicting the radiological aggravation of perilesional edema. If S-ICH expansion occurs under high pressure, the hematoma shape tends to be relatively rounder than during expansion under lower pressure. This pressure can influence the degree of local ischemic damage caused by perilesional pressure. Thus, calculating the sphericity index of a patient's hematoma can predict the extent of swelling aggravation. In our study, we confirmed that a lower sphericity index, indicating a more spherical hematoma, was significantly associated with more severe postoperative brain swelling. Additionally, it can serve as another factor associated with hematoma expansion on non-contrast CT. This finding can assist in determining appropriate surgical treatment options, particularly in situations where CT angiography is not feasible for assessing the possibility of hematoma expansion. Moreover, compared with the existing non-contrast CT signs, the sphericity index reduces inter-observer variability among clinicians, making it a reliable tool for clinical decision-making.

Consequently, using the sphericity index to more accurately predict the extent of perilesional swelling aggravation and the risk of hematoma expansion can help predict the prognosis of S-ICH and decide between conservative and surgical treatment for patients in the early stages.[23]

We hypothesized that the sphericity index would correlate with the severity of swelling aggravation and serve as a significant factor in predicting salvage DC. However, the statistical analysis did not reveal a significant correlation between the sphericity index and salvage DC. Although a significant correlation was observed between the sphericity index and swelling aggravation, as well as a strong correlation between swelling aggravation and salvage DC, the relationship between the sphericity index and salvage DC remains unclear. Several factors may have contributed to the lack of a clear correlation.

First, the relatively small sample size of 56 patients in this single-center study may have been a contributing factor. Additionally, the inclusion of only 13 salvage DC cases may have resulted in an insufficient sample size to yield significant findings.

Second, the relationship between the sphericity index and salvage DC may be nonlinear. While a linear relationship may exist between the sphericity index and swelling aggravation, and between swelling aggravation and salvage DC, the relationship between the sphericity index and salvage DC may be nonlinear.

Third, intervening variables may exist between the sphericity index and salvage DC. The correlation does not imply causation; therefore, certain intervening variables unrelated to swelling aggravation may influence the correlation between the sphericity index and salvage DC. Variables, such as the aggressiveness of the caregiver, overall patient condition, and degree of neurological deterioration can potentially influence the relationship between the sphericity index and salvage DC, leading to ambiguity.

The small sample size may limit the generalizability of the findings to larger populations. Since the swelling aggravation analysis was performed only in the surgical group, the results may differ between the conservative and other surgical treatment groups. At the time of the initial study, we examined the differences in the sphericity index between patients who underwent salvage DC and those who did not; thus, the study was conducted with a relatively small sample size. Therefore, further research that includes patients who receive conservative treatment and those who undergo other surgical treatments are necessary to enhance the representativeness of the findings. By incorporating these different treatment modalities, a more comprehensive understanding of the relationship between swelling aggravation and the sphericity index can be achieved.

CONCLUSION

S-ICH is a medical emergency that accounts for a significant proportion of strokes cases and has a high potential for severe disability. Prompt evaluation of the neurological and radiological status, and appropriate management, are crucial in these cases. Although medical management guidelines are being established, and surgical techniques continue to evolve, insufficient evidence-based guidelines for surgical indications and patient selection remain.

The sphericity index can be a valuable indicator for predicting delayed swelling aggravation and the presence of hematoma expansion. It may help in establishing surgical guidelines and assist in planning specific medication strategies for medical treatment. Further larger-scale studies are required to explore these aspects.

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