Original article

Etiologies, management, and outcomes of pediatric stroke at a tertiary care center in Thailand

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Abstract

Background: Recent developments in neuroimaging and treatments, such as thrombolysis and endovascular thrombectomy, have improved pediatric stroke diagnosis and management. However, limited contemporary data exist on stroke characteristics related to the clinical outcomes among Thai children.
Objectives: This study aimed to examine the clinical characteristics, investigations, treatments, and outcomes in pediatric Thai patients with stroke.
Methods: Children aged 28 days to 18 years with "cerebrovascular disease" recorded as the ICD-10 code and inpatient records from January 2011 to September 2022 were enrolled. The outcomes included disability at discharge (modified Rankin scale (mRS) grade 4–5), in-hospital mortality, and 2-year recurrent stroke rate.
Results: Of the 206 included patients, 53.4% had ischemic stroke, 36.4% had hemorrhagic stroke, and 10.2% had cerebral venous sinus thrombosis. The main presentations were weakness (49.5%), headache (35.4%), and altered consciousness (26.2%). The most prevalent etiologies for each stroke type were moyamoya vasculopathy in acute ischemic stroke, arteriovenous malformation in hemorrhagic stroke, and medication-related conditions such as L-asparaginase and oral contraceptive use in cerebral sinus venous thrombosis. Hemorrhagic stroke had the highest mean mRS (2.8 ± 2.2, $P < 0.001$) and in-hospital mortality (21.3%, $P < 0.001$). Only one case underwent endovascular thrombectomy.
Conclusion: Pediatric stroke in Thai children presents with diverse etiologies and clinical manifestations, with hemorrhagic stroke exhibiting the highest disability and mortality rates. These findings emphasize the need for targeted research into early diagnostic protocols, risk stratification tools, and the feasibility of advanced interventions such as endovascular thrombectomy in pediatric populations.

Keywords: Acute ischemic stroke, cerebral sinus venous thrombosis, hemorrhagic stroke, pediatric stroke.

Although pediatric stroke is relatively uncommon, it can give rise to substantially high rates of mortality and morbidity. Its incidence ranges from 2.5 to 13.5 per 100,000 individuals, the majority of which are acute ischemic strokes.[1-4] Recent advancements in diagnostic techniques and treatment options, such as magnetic resonance imaging (MRI), vascular imaging, mechanical thrombectomy, and thrombolysis, have demonstrated promise in altering pediatric stroke prognosis. However, more information is required regarding the efficacy of these interventions in pediatric populations.[5] The International Pediatric Stroke Study conducted the largest and most comprehensive cohort study of pediatric stroke cases. This study included the Asian population, but the number of cases was small. Furthermore, this report regarding pediatric stroke in the Thai population was performed more than 15 years ago.[6] Therefore, we conducted a retrospective study on pediatric stroke, including acute ischemic stroke (AIS), hemorrhagic stroke (HS), and cerebral venous sinus thrombosis (CVST), at a tertiary care center in Thailand. The objective of this study was to enhance our understanding of the clinical presentations of pediatric

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stroke, provide an update on the investigations and treatments, study the outcomes of each stroke subtype, and use the findings from this study to improve pediatric stroke management.

Materials and methods

This study was reviewed and approved by the institutional review board of the Faculty of Medicine, Chulalongkorn University, Thailand (IRB no. 0656/65). A waiver of informed consent was obtained because of the retrospective nature of this study.

Study population and data collection

This retrospective study was conducted on patients with pediatric stroke aged 28 days to 18 years from January 2011 to September 2022 at King Chulalongkorn Memorial Hospital, Thai Red Cross Society, Thailand. We searched for relevant ICD-10 codes and identified patients with cerebrovascular disease. To ensure diagnostic accuracy, each case identified via ICD-10 coding was individually reviewed by examining the patient's electronic medical records, including the clinical notes, imaging reports, and discharge summaries, to confirm the diagnosis of cerebrovascular disease.

Patients' data were collected from electronic medical records and included age, sex, ethnicity, comorbidities, time to diagnosis (from the symptom onset), clinical presentation, neuroimaging findings, treatment, and outcomes. Neonatal cases, perinatal stroke, presumed neonatal stroke, trauma-related cerebrovascular disorders, and cases with incomplete data were excluded from this study. The study flow is illustrated in **Figure 1.**

Definitions and diagnosis

Stroke definition and diagnosis

Pediatric stroke, as defined by the American Heart Association (AHA), is a cerebrovascular event that is characterized by the sudden interruption or reduction of blood flow to the brain, leading to brain function impairment. It includes three main subtypes, namely AIS, HS, and CVST.[7]

We classified our included cases according to whether the underlying cause was ischemic, hemorrhagic, or CVST, as detailed in the National Institutes of Health common data elements.[8]

AIS was diagnosed by an acute onset of neurological signs or symptoms that lasted more than 24 h, which was attributable to focal brain infarction or hemorrhage. These are accompanied or confirmed by computed tomography (CT), MRI studies, or autopsy results that revealed changes consistent with brain infarction.[9]

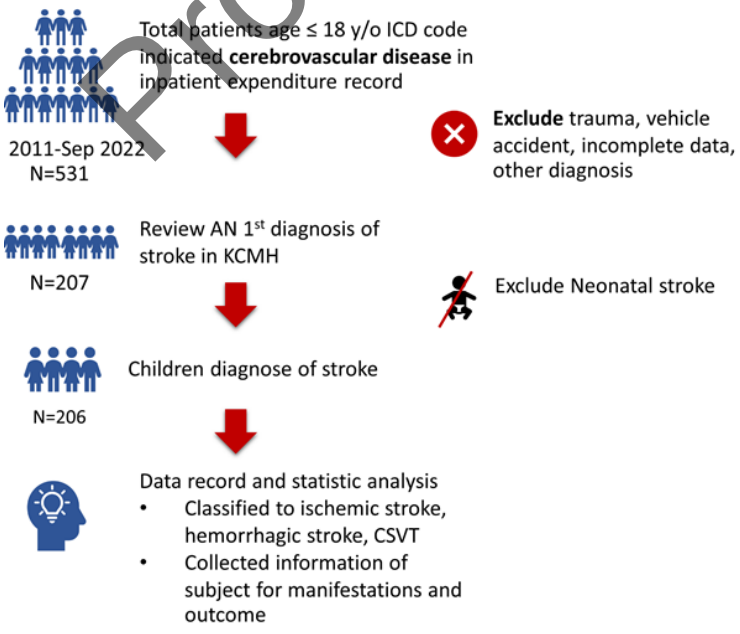

Figure 1. Study flow.

HS comprised nontraumatic, spontaneous intracerebral hemorrhage, intraventricular hemorrhage, and subarachnoid hemorrhage.

CVST was defined by the involvement of the intracranial venous sinuses, the deep venous system, and cortical veins that drain into the major intracranial sinuses.[9]

These diagnostic approaches are consistent with the definitions of the Global Stroke Statistics 2019 and 2022.[10, 11]

Inpatient stroke

Inpatient stroke refers to a stroke that occurred while a patient was hospitalized.

Time to diagnosis

Time to diagnosis is defined as the interval between the documented onset of neurological symptoms and the definitive diagnosis of stroke.

Etiologies

The etiologies included arteriopathies, cardiac disease, hypercoagulable states, acute systemic conditions, hematology and oncology conditions, chronic head and neck disorders, genetic and metabolic diseases, and medications or treatment-related conditions.[12]

Investigations

The patients' first neuroimaging data were recorded, which included CT, MRI, computed tomography perfusion, and computed tomography angiography (CTA). Imaging characteristics were described as the ischemic area and territory, and stroke complications found on neuroimaging were recorded.

The imaging results were reported by various on-service radiologists as part of a hospital service, as this is a retrospective study. Reports of irrelevant imaging findings were not included in the analysis.

Treatments

Treatments were classified into pharmacological and interventional management. Pharmacological treatments included antithrombotics, such as heparin, warfarin, and enoxaparin, and antiplatelet treatments, which included aspirin. Another treatment was the blood component, where interventional treatments included thrombectomy, embolization, and surgical treatment.

Outcomes

We recorded the outcomes, including stroke complications, disability using the modified Rankin scale (mRS) at discharge, in-hospital mortality, and recurrent rates of stroke at 2 years. The definition of mRS is provided in **Supplementary Table S1**.

Statistical analysis

Continuous data were assessed using the mean ± standard deviation, and categorical data were expressed as numbers and percentages. Unpaired Student *t*-tests and chi-square tests were used to determine the differences between groups. $P < 0.05$ was considered statistically significant.

Results

Overview of all stroke subtypes

A total of 531 children with cerebrovascular diseases were identified by searching the ICD-10 codes. After applying the exclusion criteria, including trauma-related cases, motor vehicle accidents, neonatal stroke, and incomplete medical records, 325 cases were excluded. This resulted in a final study cohort of 206 children. Among them, 53.4% (n = 110) had AIS, 36.4% (n = 75) experienced HS, and 10.2% (n = 21) had CVST. The patients' demographic data are presented in **Table 1**. The mean age was the lowest in AIS compared to those of patients with HS and CVST (7.6 *vs*. 10.9 *vs*. 10.0 years, respectively, $P < 0.001$). In addition, there was no significant difference in sex distribution among the stroke subtypes. Most of the patients with stroke were referred from other hospitals, in which patients with HS exhibited the highest referral rate compared to that of patients with AIS and CVST (70.7% *vs*. 56.4% *vs*. 38.1%, respectively, $P = 0.027$). However, the rate of in-hospital stroke subtypes did not differ significantly. CVST had the highest rate of obesity compared to that of the other stroke subtypes (19.0%, $P < 0.006$).

Time to diagnosis and clinical presentation

Time to diagnosis differed among the stroke subtypes ($P < 0.001$). Patients with AIS had a greater delay to diagnosis than the other subtypes, more than 4.5 h in 48.2% of cases (n = 53). HS presented a time to diagnosis within 4.5 h in 62.7% of cases (n = 47) and was unknown in 6.7% of cases (n = 5) **(Table 1).**

Table 1. Patients' demographics (n = 206) and co-morbidity.

	AIS n (%)	Hemorrhagic stroke n (%)	CVST n (%)	*P*-value
Total cases	n = 110	n = 75	n = 21	
Age, mean ± SD (years)	7.6 ± 5.6	10.9 ± 6.0	10.0 ± 5.6	< 0.001
Male	59 (53.6)	36 (48.0)	11 (52.4)	0.75
Ethnicity				
Asian	109 (99.1)	73 (97.3)	21 (100.0)	0.521
African	1 (0.9)	2 (2.7)	0 (0.0)	
Comorbidity				
Obesity	6 (5.5)	1 (1.3)	4 (19)	0.006
Dyslipidemia	2 (1.8)	0 (0)	1 (4.8)	0.246
Metabolic syndrome	6 (5.5)	0 (0)	0 (0)	0.067
Anemia	4 (3.6)	1 (1.3)	2 (9.5)	0.141
Polycythemia	3 (2.7)	2 (2.7)	0 (0)	0.747
Dehydration	1 (0.9)	0 (0)	1 (4.8)	0.144
Time to diagnosis				
Unknown	25 (22.7)	5 (6.7)	6 (28.6)	< 0.001
Within 4.5 hours	32 (29.1)	47 (62.7)	7 (33.3)	
Morethan 4.5 hours	53 (48.2)	23 (30.7)	8 (38.1)	

AIS, Acute ischemic stroke; CVST, cerebral venous sinus thrombosis; SD, standard deviation.

In-hospital strokes were diagnosed within 4.5 h in 67.3% of cases (n = 33), which was significantly higher than those of patients referred from other hospitals (38.2%, n = 47) or those presenting directly to the emergency room (16.0%, n = 4) ($P < 0.001$).

Clinical presentation

Table 2 and **Figure 2** summarize the clinical manifestations. Focal neurological deficit was the most common overall pediatric stroke presentation (58.7%, n = 121), followed by headache (35.4%, n = 73), seizure (32.5%, n = 67), and alteration of consciousness (26.2%, n = 54).

Seizure

Seizure types varied among the stroke subtypes. Focal seizures were most prevalent in AIS, 30.0% (n = 10), whereas patients with HS tended to have generalized seizure**s** (either generalized tonic-clonic or generalized tonic seizure**s**), 10.7% (n = 8). **Figure 3** shows bar charts representing the type of seizure among each stroke subtype. In CVST, generalized tonic and generalized clonic seizures were the most common seizure presentations. Status epilepticus was only noted in two patients with AIS and none with HS or CVST.

Stroke neuroimaging

At diagnosis, CT without contrast was performed in 85.6% (n = 176) of the cases, MRI in 15.3% (n = 32), CTA in 6.7% (n = 14), and magnetic resonance angiography (MRA) in 4.3% (n = 9). Brain MRI was performed as the second imaging study in 37.3% of cases (n = 76) and MRA in 24.9% (n = 50).

Stroke complications imaging characteristics

In AIS and HS, the most common complication found on neuroimaging was a midline shift (10.0% in AIS and 30.7% in HS). Hydrocephalus was the second most common imaging complication in HS (29.3%, n = 22). Regarding brain herniation types, uncal herniation was the most common in AIS (7.3%) and was also frequent in HS (9.3%), while subfalcine herniation was slightly more prevalent in HS (8.8%) than in AIS (5.5%).

In CVST, the most prevalent complication was bleeding transformation (23.8%, n = 5), and there was no brain herniation found in CVST via imaging in this study cohort.

Table 2. Clinical presentation.

	n (%)
Clinical	
Focal neurological deficit	121 (58.7)
Weakness	102 (49.5)
Ophthalmoplegia	3 (1.5)
Facial palsy	26 (12.6)
Dysarthria	6 (2.9)
Speech	16 (7.8)
Visual problem	7 (3.4)
Ataxia	3 (1.5)
Paresthesia	6 (2.9)
Others	9 (4.4)
Diffuse neurological deficit	
Alteration of consciousness	54 (26.2)
Behavioral change	1 (0.5)
Seizure	
Generalize tonic-clonic	20 (9.7)
Generalize tonic	11 (5.3)
Generalize clonic	9 (4.4)
Focal tonic	5 (2.4)
Focal clonic	18 (8.7)
Focal to secondarily generalize	2 (1.0)
Status epilepticus	1 (0.5)
Other	5 (2.4)
Headache	73 (35.4)
Nausea/vomitting	40 (19.4)
Fever	13 (6.3)

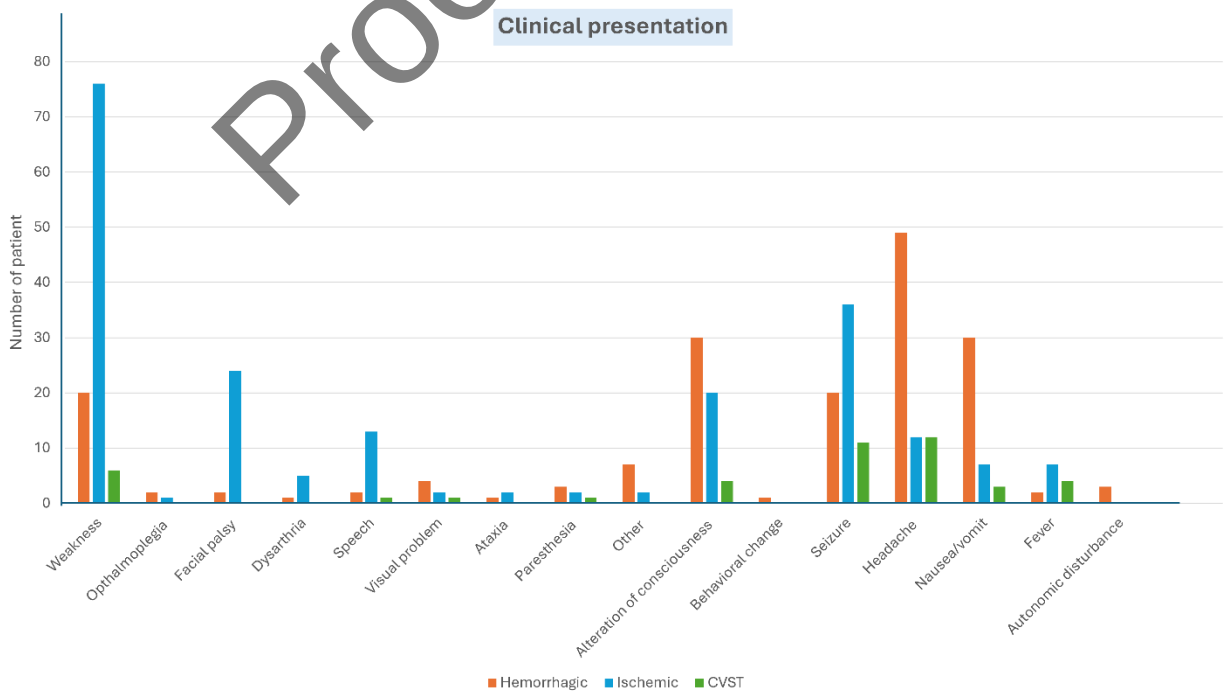

Figure 2. Neurological deficits for each stroke subtype.

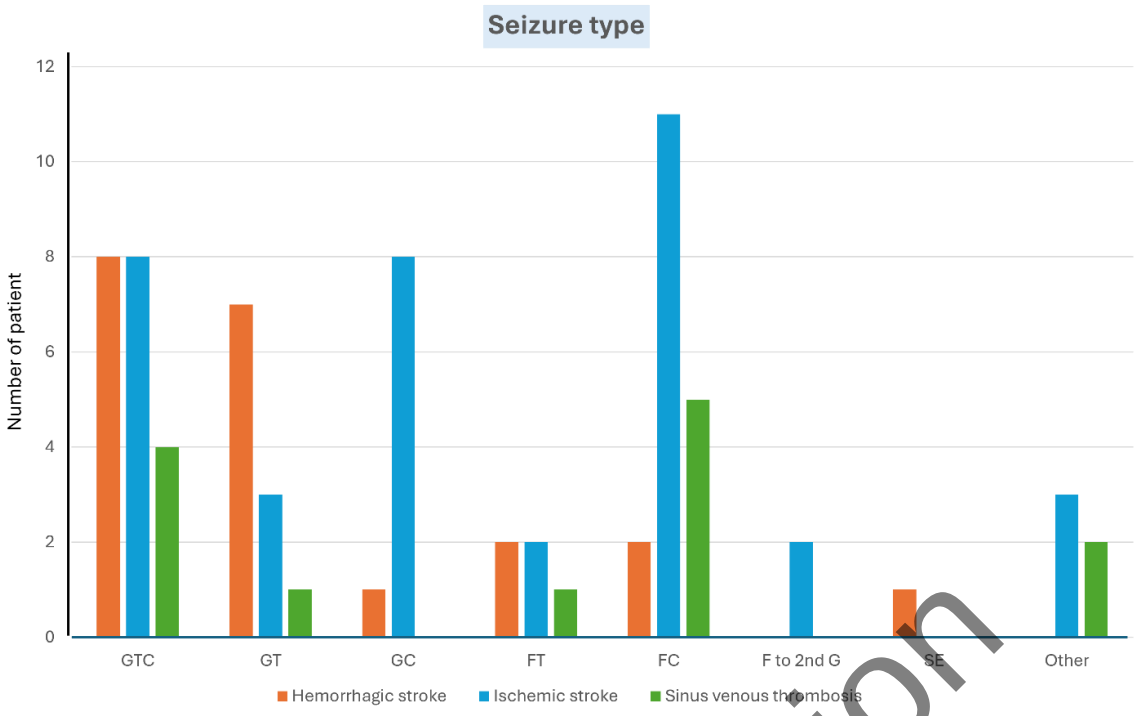

Figure 3. Bar charts represent the type of seizure among each stroke subtype.

Outcomes and prognosis

The number of patients with a discharge outcome of normal was 31.8% (n = 35) in AIS cases, 57.3% (n = 43) in HS cases, and 66.7% (n = 14) in CVST cases. The death rate was highest among HS cases (21.3%, n = 16), which was statistically significant ($P < 0.001$), followed by 5.5% (n = 6) in AIS cases. No patient died from CVST in our cohort. The mean mRS scores demonstrated significant variation among the groups ($P < 0.001$), with HS exhibiting the highest score of 2.8, followed by AIS with a score of 1.8, and CVST with a score of 1.

The most common stroke complication was epilepsy, which is the most prevalent complication recorded among all stroke subtypes: 15.5% (n = 17) in AIS, 14.7% (n = 11) in HS, and 14.3% (n = 3) in CVST. Joint contracture was found in 2.7% (n = 3) of AIS cases, 1.3% (n = 1) of HS cases, and none in CVST. The second most common complication in HS was visual problems in 4.0% of cases (n = 3). Other complications are presented in **Table 3.**

We compared the stroke outcomes based on the time of onset and diagnosis. Our analysis revealed that patients diagnosed more than 4.5 h after the onset of stroke commonly experienced abnormal neurological consequences, which was 59.5% of cases (n = 50). Among patients with an unknown time of stroke onset, the mortality rate was highest at 17.1% (n = 6). In comparison, patients who were diagnosed within 4.5 h of symptom onset had a slightly lower mortality rate of 15.1% (n = 13) **(Table 4).**

The overall 2-year recurrent rate of AIS was 27.3% (n = 30), HS was 8.0% (n = 6), and CVST was 4.8% (n = 1).

Acute ischemic stroke

Patients with AIS were 53.6% male (n = 59) and were further classified as having either a thrombosis (46.4%, n = 51) or an embolic stroke (53.6%, n = 59). The mean age was 7.6 years old. Their nationalities were Asian, 99.1% (n = 109) (with only one African patient). The majority of patients with AIS (56.4%, n = 62) were referred from other hospitals, 22.7% (n = 25) happened in the hospital, and 15.5% (n = 17) presented to the emergency room.

Among patients with AIS, comorbid conditions were infrequent. Obesity and metabolic syndrome were observed in 5.5% of cases each (n = 6), followed by anemia in 3.6% (n = 4), polycythemia in 2.7% (n = 3), dyslipidemia in 1.8% (n = 2), and dehydration in 0.9% (n = 1) **(Table 1).**

Clinical presentation

The most common initial presentations were weakness (n = 79, 71.8%), seizure (n = 36, 32.7%), alteration of consciousness (18.2%), and diffuse neurological deficit (n = 20, 18.2%). Other neurological deficits are shown in **Figure 2.**

Table 3. Stroke outcome.

	AIS n = 110 (%)	Hemorrhagic stroke n = 75 (%)	CVST n = 21 (%)	*P*- value
MRS score and status at discharge				
Mean MRS score ± SD	1.8 ± 1.7	2.8 ± 2.2	1.0 ± 1.6	<0.001
Median MRS (IQR)	2 (0, 3)	2 (1, 4)	0 (0.0)	<0.001
Normal	35 (31.8)	16 (21.3)	14 (66.7)	
Abnormal	69 (62.7)	43 (57.3)	7 (33.3)	
Death	6 (5.5)	16 (21.3)	0 (0.0)	<0.001
Complications				
Epilepsy	17 (15.5)	11 (14.7)	3 (14.3)	
Joint contracture	3 (2.7)	1 (1.3)	0 (0.0)	
Movement	1 (0.9)	0 (0.0)	0 (0.0)	
Visual problem	0 (0.0)	3 (4.0)	0 (0.0)	
Cognitive decline	1 (0.9)	0 (0.0)	0 (0.0)	

CVST, cerebral venous sinus thrombosis; IQR, interquartile range; MRS, Modified rankin scale for neurologic disability; SD, standard deviation.

Table 4. Outcomes and time to diagnosis.

Status at discharge	Unknown n =365	Within 4.5 hours n=86	More than4.5 hours n=84	*P*- value
Full recovery n(%)	109 (275.87)	24 (27.9)	31 (36.9)	0.076
Abnormal n(%)	20 (557.61)	49 (57.0)	50 (59.5)	
Death n(%)	6 (167.71)	13 (15.1)	3 (3.6)	

Risk factors

Among all patients, AIS-related risk factors were identified in 85.5% (n = 94). The most common etiologies of AIS in our cohort were moyamoya disease (31.8%, n = 35), post-cardiac surgery (12.7%, n = 14), and non-cyanotic heart diseases (9.1%, n = 10). Moreover, underlying hematologic conditions were relatively uncommon. Genetic causes were found in 2.7% (n = 3), including one case with a rare disease mutation in the *SLC19A2* gene and two cases with mitochondrial etiology. The other detailed etiologies are presented in **Table 5**.

Apart from the underlying etiologies, stroke can occur from treatment complications or other acute conditions.

Acute ischemic stroke neuroimaging

In the cases of AIS, the frontal area was affected in 47.3% (n = 52), the parietal area in 45.5% (n = 50), the temporal area in 36.4% (n = 40), the basal ganglia in 30.0% (n = 33), the occipital region in 23.6% (n = 26), the cerebellar region in 5.5% (n = 6), and the brain stem in 3.6% (n = 4). The vascular territories that were involved primarily included the middle cerebral artery (MCA) in 70.0% (n = 77), internal cerebral artery in 27.3% (n = 30), anterior cerebral artery in 24.5% (n = 27), posterior cerebral artery in 14.5% (n = 16), posterior inferior cerebellar artery (PICA) in 0.9 % (n = 1), and anterior inferior cerebellar artery (AICA) in 0.9% (n = 1) **(Table 6)**.

Treatment

Aspirin was the primary treatment of AIS in our cohort, including 52.7% of cases (n = 58). Other medical therapies included blood transfusion (1.8%, n = 2) and anticoagulants (25.5%, n = 28), which comprised enoxaparin (18.2%, n = 20) and heparin (7.3%, n = 8) **(Table 7).**

Patients with AIS required surgical treatment in 25.5% of cases (n = 28). The surgical procedures for AIS included superficial temporal artery to middle cerebral artery bypass (STA-MCA) (10.9%, n = 12), encephaloduroarteriosynangiosis (9.1%, n = 10), and craniectomy (3.6%, n = 4). Mechanical thrombectomy was only performed in one patient with AIS.

Hemorrhagic stroke

Among patients with HS, 48.0% were male (n = 36). The mean age was 10.9 years old. Their nationality was primarily Asian (97.3%, n = 73), with only 2.7% (n = 2) that were African. Similar to that of AIS, most of the patients with HS were referred from other hospitals (70.7%, n = 53), 24.0% (n = 18) happened in hospital, and 4.0% (n = 3) presented to the emergency room.

Most patients with HS had no documented comorbidities. Among those with identifiable conditions, 2.7% (n = 2) had polycythemia, 1.3% (n = 1) had obesity, and 1.3% (n = 1) had anemia **(Table 1)**.

Clinical presentations

In the study, most patients with HS exhibited headaches as the primary symptom (65.3%, n = 49). This was followed by reports of nausea and vomiting (45.3%, n = 34), focal neurological deficit (45.3%, n = 34), diffuse neurological deficit (40.0%, n = 30), and seizure (26.7%, n = 20).

Risk factors

Arteriovenous malformation was the most common etiology of HS in our cohort, which occurred in 49.3% (n = 37) of the patients. Other causes included brain tumors (9.3%, n = 7), acute systemic conditions, such as sepsis (9.3%, n = 7), brain aneurysm (6.7%, n = 5), hematologic malignancy (4.0%, n = 3), and a genetic cause (1.3%, n = 1), which was identified as Wiskott–Aldrich syndrome. Unknown causes only accounted for 6.7% (n = 5) of HS **(Table 5).**

Hemorrhagic stroke neuroimaging

Intracerebral hemorrhage was the most prevalent complication found on neuroimaging in HS (80.0%, n = 60). Intraventricular hemorrhage was the second most common (42.7%, n = 32), and the parietal area was primarily affected in 29.3% (n = 22). Subarachnoid hemorrhage occurred in 13.3% (n = 10), and subdural hemorrhage was only found in 6.7% (n = 5) **(Table 6)**.

Treatment

In HS, the most common treatment was surgical management, which included craniectomy (32%, n = 24), endovascular intervention (28%, n = 21), embolization (28%, n = 21), lesionectomy (24%, n = 18), and extraventricular drainage and shunt placement (22.7%, n = 17). Non-surgical management in HS included blood component transfusion for bleeding tendency (14.7%, n = 11), blood transfusion (14.7%, n = 11), and aspirin (1.3%, n = 1) **(Table 7)**.

Cerebral venous sinus thrombosis

Demographic data

Among patients with CVST, 52.4% were male (n = 11). The mean age was 10 years old. All of them were of Asian origin. In addition, 38.1% (n = 8) were referred from other hospitals, 28.5% (n = 6) happened in hospital, and 23.8% (n = 5) presented to the emergency room.

Regarding comorbidities, obesity was notably more prevalent in patients with CVST (19%, n = 4) compared to those with AIS and HS (P = 0.006). Moreover, 4.8% (n = 1) had dyslipidemia, 9.5% (n = 2) had anemia, and 4.8% (n = 1) had dehydration **(Table 1).**

Clinical presentation

Most patients with CVST presented with nonspecific neurological symptoms (61.9%, n = 13), such as headache, nausea, vomiting, and fever. The second most common presentations were seizures (52.4%, n = 11) and focal neurological deficits (38.1%, n = 8). The bar chart of the CVST clinical presentations is presented in **Figure 2.**

Risk factors

The most common risk factor of CVST in our cohort was from medical treatment (42.9%, n = 9). The second and third most common risk factors were a hypercoagulable state (28.6%, n = 5) (positive antiphospholipid and lupus anticoagulant) and an underlying hematologic malignancy (14.3%, n = 3), respectively. The detailed risk factors are described in **Table 5.**

Cerebral venous sinus thrombosis neuroimaging

The superficial venous system was the most prevalent complication found on neuroimaging in our cohort, 100% (n = 21). The deep venous system was found in 9.5% (n = 2), and the cavernous sinus in 4.8% (n = 1) **(Table 6).**

Treatment

The medical treatments for CVST were anticoagulant (enoxaparin) (61.9%, n = 13) and blood transfusion (28.6%, n = 6). Only one patient received surgical treatment (4.8%, n = 1), which was a shunt replacement **(Table 7).**

Table 5. Stroke risk factors (etiologies).

	AIS n = 110 (%)	Hemorrhagic stroke n = 75 (%)	CVST n = 21 (%)
Unknown	16 (14.5)	5 (6.7)	4 (19.0)
Arteriopathies			
Moya moya	35 (31.8)	1 (1.3)	0 (0.0)
Post-infectious arteriopathy	2 (1.8)	0 (0.0)	0 (0.0)
Arterial dissection	1 (0.9)	0 (0.0)	0 (0.0)
Others	1 (0.9)	0 (0.0)	0 (0.0)
Cardiac diseases			
Cyanotic heart disease	6 (5.5)	1 (1.3)	0 (0.0)
Non-cyanotic heart disease	10 (9.1)	0 (0.0)	0 (0.0)
Arrhythmia	2 (1.8)	0 (0.0)	0 (0.0)
Post cardiac surgery	14 (12.7)	2 (2.7)	0 (0.0)
Post cardiac catheterization	6 (5.5)	1 (1.3)	0 (0.0)
Endocarditis	0 (0.0)	0 (0.0)	1 (4.8)
Others	1 (0.9)	0 (0.0)	0 (0.0)
Hypercoagulable disorders			
Protein C deficiency	2 (1.8)	0 (0.0)	0 (0.0)
Protein S deficiency	3 (2.7)	0 (0.0)	0 (0.0)
Hyperlipoproteinemia	3 (2.7)	0 (0.0)	0 (0.0)
Antiphospholipid	2 (1.8)	0 (0.0)	2 (14.3)
Lupus anticoagulant	2 (1.8)	1 (1.3)	3 (14.3)
Others	1 (0.9)	2 (2.7)	0 (0.0)
Acute systemic condition			
Sepsis	3 (2.7)	7 (9.3)	0 (0.0)
Septic emboli	2 (1.8)	1 (1.3)	0 (0.0)
Shock	1 (0.9)	2 (2.7)	0 (0.0)
Oncological condition			
Hematologic malignancy	0 (0.0)	3 (4.0)	3 (14.3)
Others	1 (0.9)	1 (1.3)	0 (0.0)
Chronic head and neck disorder			
Brain tumor	1 (0.9)	7 (9.3)	0 (0.0)
Aneurysm	0 (0.0)	5 (6.7)	0 (0.0)
Arteriovenous malformation	0 (0.0)	37 (49.3)	0 (0.0)
Others	0 (0.0)	1 (1.3)	0 (0.0)
Genetic	3 (2.7)	1 (1.3)	0 (0.0)
Treatment-related			
Medication	1 (0.9)	2 (2.7)	9 (42.9)
ECMO	1 (0.9)	0 (0.0)	0 (0.0)
Others	0 (0.0)	2 (2.7)	0 (0.0)

ECMO, extracorporeal cardiopulmonary support in critical care.

Table 6. Imaging characteristics.

Acute ischemic stroke (vascular territory)	**n (%)**
ICA	30 (27.3)
ACA	27 (24.5)
MCA	77 (70.0)
PCA	16 (14.5)
PICA	1 (0.9)
AICA	1 (0.9)
BA	2 (1.8)
SCA	1 (0.9)
Acute ischemic stroke (anatomical distribution of stroke)	
Frontal	52 (47.3)
Parietal	50 (45.5)
Occipital	26 (23.6)
Temporal	40 (36.4)
Thalamic	5 (4.5)
Basal ganglion	33 (30.0)
Brain stem	4 (3.6)
Cerebellar	6 (5.5)
Hemorrhagic stroke	
Intracerebral hemorrhage	60 (80.0)
Intraventricular hemorrhage	32 (42.7)
Subarachnoid hemorrhage	10 (13.3)
Subdural hemorrhage	5 (6.7%)
Cerebral venous sinus thrombosis	**n (%)**
Superficial venous system	21 (100.0)
Deep venous system	2 (9.5)
Cavernous sinus	1 (4.8)

ACA, anterior cerebral artery; AICA, anterior inferior cerebellar artery; BA, basilar artery; ICA, internal carotid artery; PCA, posterior cerebral artery; PICA, posterior inferior cerebellar artery; SCA, superior cerebellar artery.

Table 7. Treatment.

	Ischemic stroke n (%)	**Hemorrhagic stroke n (%)**	**CSVT n (%)**
Medical treatment			
Aspirin	58 (52.7)	1 (1.3)	1 (4.8)
Enoxaparin	20 (18.2)	0 (0.0)	13 (61.9)
Heparin	8 (7.3)	0 (0.0)	1 (4.8)
Blood transfusion	2 (1.8)	11 (14.7)	6 (28.6)
Other	8 (7.3)	4 (5.3)	0 (0)
No medications	14 (12.7)	59 (78.7)	0 (0)
Surgical treatment			
Craniectomy	4 (3.6)	24 (32.0)	0 (0.0)
Lesionectomy	0 (0.0)	18 (24.0)	0 (0.0)
EVD/shunt	2 (1.8)	17 (22.7)	1 (4.8)
EDAS	10 (9.1)	0 (0.0)	0 (0.0)
STA-MCA	12 (10.9)	0 (0.0)	0 (0.0)
Intervention			
Embolization	0 (0.0)	21 (28.0)	0 (0.0)
Thrombectomy	1 (0.9)	0 (0.0)	0 (0.0)

ASA, aspirin; EDAS, encephaloduroarteriosynangiosis; EVD, extraventricular drainage; STA-MCA, superficial temporal artery to middle cerebral artery bypass.

Discussion

The incidence of pediatric stroke varies among ethnicities, and our study provides valuable insights into its characteristics within the Thai population. **Figure 4** shows the graphical abstract for this study. While AIS remains the most common stroke subtype, followed by HS and CVST, our findings reveal a slightly lower proportion of AIS cases (53.0%) compared to those previously reported (70.0%–80.0%) from Canada and Denmark.[2, 3] A cohort from Taiwan shows a different proportion of HS (43.6%), which was more prevalent than AIS (36.0%).[13] This discrepancy warrants further investigation and may reflect regional differences in risk factors, genetic predisposition, or environmental influences.[14]

The management of pediatric stroke presents unique challenges compared to that of adult stroke, particularly in terms of diagnosis timing. Unlike adults, where the last known normal state is often clearly identifiable, childhood stroke usually manifests with nonspecific symptoms, which leads to diagnostic delays and potentially unfavorable outcomes.[7] In this cohort, more than half of the patients were diagnosed beyond the critical 4.5-h therapeutic window from symptom onset or had an unknown time of onset. This delay reflects a broader trend observed in international pediatric stroke studies. For instance, the Canadian Pediatric Ischemic Stroke Registry by deVeber GA, *et al*. reported a median time to diagnosis of 22.7 h, while Gabis, *et al*. documented an average delay of 35.7 h.[2, 15] These findings highlight the persistent global challenge of timely stroke recognition in children, which is often compounded by atypical presentations and limited access to pediatric stroke expertise. Among our patients, pediatric stroke presentations extend beyond focal neurological deficits to include headaches and alterations of consciousness, especially in cases of AIS. This diversity of symptoms, coupled with the presence of stroke mimics, such as infections, demyelinating diseases, or posterior reversible encephalopathy syndrome, contributes to the complexity of timely diagnosis. The delayed or unknown onset of symptoms typical in pediatric stroke emphasizes the need for heightened awareness among healthcare providers and tailored diagnostic approaches. Our findings underscore the importance of considering stroke in the differential diagnosis when children present with a wide range of neurological symptoms, even in the absence of classic stroke presentations. This approach may help reduce diagnostic delays and improve the outcomes of pediatric stroke cases.[5]

Stroke investigations have improved over the past two decades. Compared to a prior report from Thailand, our study reveals a nearly twofold increase in the identification of etiologies (previous report: AIS 57.0% *vs*. our report: AIS 85.5%).[6] The number of etiologic findings was similar to that of the Taiwan cohort.[14]

A Canadian cohort study reported arteriopathy as the most common etiology for pediatric AIS, with the common subtypes being dissection and post-varicella angiopathy.[2] Our findings align with this, as arteriopathy was also identified as our study's most prevalent risk factor. However, the subtype distribution differed, with moyamoya being the most common subtype, while postinfectious arteriopathy and dissection were only observed in two cases. The difference in ethnicity might explain this. Moreover, a study from Hong Kong in 2004 found that moyamoya was the most common subtype.[15]

The field of endovascular thrombectomy in childhood stroke is still evolving. Recent reviews have suggested favorable outcomes for pediatric patients with AIS undergoing this procedure. However, more robust data are required to establish clear guidelines for its use in pediatric populations.[17, 18] In our study, mechanical thrombectomy was only performed in one patient with AIS, which limits our ability to assess its effectiveness. This finding reflects the broader challenge of implementing advanced neurointerventional procedures in pediatric populations, particularly in resource-limited settings.

This study corroborates previous literature regarding stroke outcomes in pediatric populations. The overall mortality rate in pediatric stroke typically ranges from 14.0% to 40.0%.[19] We found that HS resulted in the highest morbidity and mortality among stroke subtypes, which is consistent with previous studies.[20] This outcome emphasizes the critical nature of HS and the need for rapid intervention. Moreover, CSVT has the best morbidity and mortality prognosis, especially if the patient received anticoagulant treatment.[21]

Our cohort has a higher rate of recurrent AIS incidence than previous reports (6.8%).[7] This might be explained by the higher incidence of arteriopathy, which tends to increase the chance of recurrence. The AHA states that arteriopathy leads to a three to fivefold chance of AIS recurrence.[7]

Logically, the mortality rate should be lower in patients who present within 4.5 h to receive prompt and appropriate medical intervention.[22] However, our findings contrasted with this concept. The mortality rate was highest among children who presented within 4.5 h or with an unknown time of onset, which may be explained by the severity of the neurological deficit that brought the patients in this group to the hospital. As we aim to improve the timing of diagnosis to improve outcomes, the reasons behind this should be investigated further.

Epilepsy was the most common complication of all stroke subtypes, thus highlighting the need for long-term neurological follow-up in pediatric stroke survivors. Furthermore, cognitive complications may be underestimated in our cohort, as systematic evaluations of visual and cognitive function were not performed in all patients.

Our study has several limitations. Its retrospective design may introduce inherent biases, including selection bias and missing data. To minimize this, we excluded cases with incomplete or missing key clinical information, which improved data reliability and consistency. However, this approach may have resulted in the omission of atypical or less well-documented cases, thereby potentially introducing selection bias. In addition, the study population was drawn from a tertiary care hospital, where patients are typically more complex and are often referred from other institutions, which may limit the generalizability of our findings. The reliance on electronic medical records also poses a risk of underreporting certain variables. Future prospective studies are warranted to validate and expand upon these findings.

The findings of this study highlight the urgent need for standardized protocols in the management of pediatric stroke in Thailand. The delays in diagnosis and referral reveal substantial gaps in the early recognition thereof, especially in non-tertiary settings. Establishing national guidelines that encourage timely neuroimaging, standardize the use of stroke assessment scales, and promote the early involvement of pediatric neurologists could lead to improved patient outcomes. Moreover, the high prevalence of seizures and long-term disabilities among patients with HS indicates a need for increased access to rehabilitation services and long-term neurodevelopmental follow-up. These findings may support policy initiatives aimed at integrating pediatric stroke care into broader child health strategies, which should include training programs for frontline healthcare providers and investment in regional stroke networks.

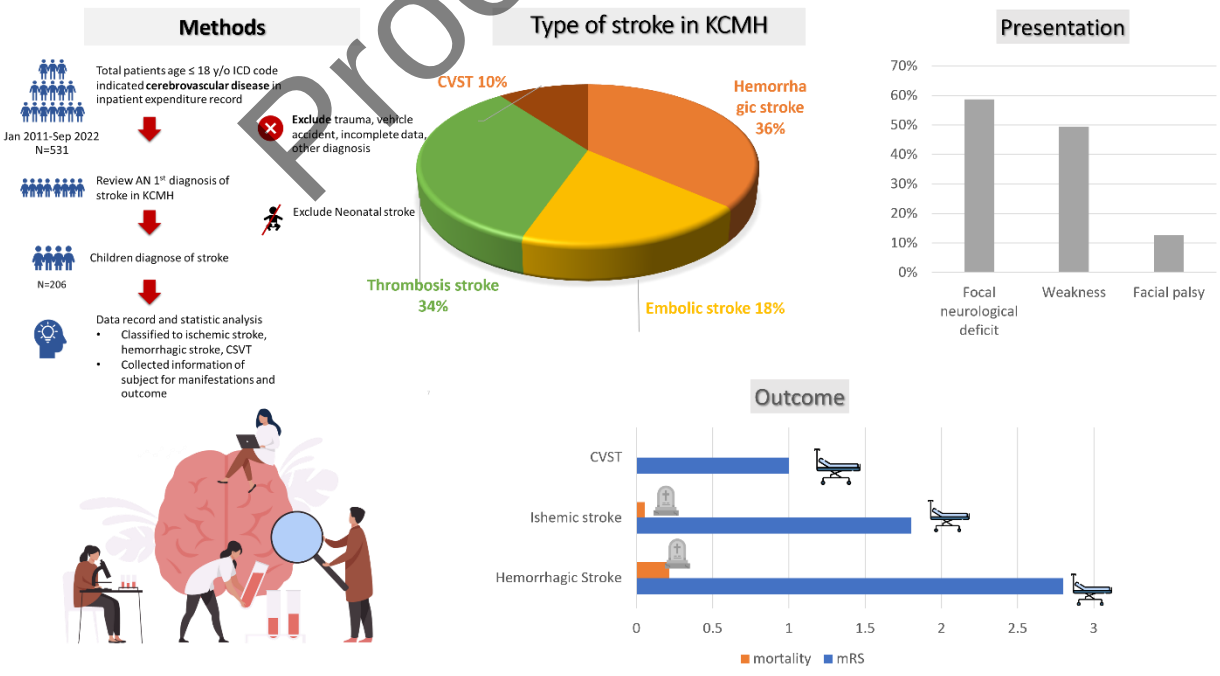

Figure 4. Graphical abstract illustrates the main concept of this study.

Conclusion

Pediatric stroke in Thai children presents with diverse etiologies and clinical manifestations, with HS exhibiting the highest rates of disability and in-hospital mortality. Despite advancements in neuroimaging, delayed diagnosis remains prevalent, particularly among referred cases, thus highlighting the need for improved early recognition protocols. The limited use of endovascular thrombectomy reflects a gap in access to advanced interventions. These findings support the development of national pediatric stroke guidelines that are focused on timely neuroimaging, standardized assessment tools, and multidisciplinary care pathways. Expanding rehabilitation services and long-term neurological follow-up, especially for HS survivors, should be prioritized in policy planning.

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Conflict of interest statement

All authors have completed and submitted the International Committee of Medical Journal Editors Uniform Disclosure Form for Potential Conflicts of Interest. None of the authors has any conflict of interest to disclose.

Data sharing statement

All data generated or analyzed during the present study are included in this published article. Further details are available for noncommercial purposes from the corresponding author upon reasonable request.

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