

Early Outcomes and Etiological Correlates of Anti-Epileptic Drug Use in Pediatric Status Epilepticus: A Prospective Observational Study

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Abstract

Background: Status epilepticus (SE) is a critical pediatric neurological emergency marked by prolonged or recurrent seizures without recovery of consciousness, associated with significant morbidity and mortality. Understanding clinico-etiological factors and treatment response is essential for timely and effective management. **Materials and Methods:** This prospective observational study was conducted over 12 months and included 100 children aged 1 month to 18 years with convulsive SE. Data were collected on demographics, etiology, seizure characteristics, anti-epileptic drug (AED) use, need for critical care interventions, and early outcomes. Statistical analysis was performed using SPSS v22, with chi-square tests applied for categorical variables ($p < 0.05$ considered significant). **Results:** The most commonly affected age group was 1–5 years (36%), with a male predominance (60%). Generalized tonic-clonic seizures accounted for 87% of cases. Acute symptomatic etiology (53%)—notably CNS infections—slightly exceeded SE in known epileptics (47%). Seizure control within one hour was achieved in 88% of patients. A strong correlation was observed between seizure duration and outcome: 96% resolution in <15-minute seizures versus 64% in those >30 minutes ($p = 0.001$). Children receiving 1–2 AEDs showed 100% resolution, while those requiring ≥ 5 AEDs had poor control and higher progression to refractory/super-refractory SE ($p = 0.001$). Ventilatory and inotropic support were also significantly associated with poor outcomes. FIRES, stroke, and genetic etiologies emerged as predictors of refractory courses. **Conclusion:** Prompt seizure control using minimal AEDs, early identification of high-risk etiologies, and appropriate critical care support significantly improve outcomes in pediatric SE.

Keywords: Status epilepticus, pediatric seizures, anti-epileptic drugs, seizure outcome, acute symptomatic etiology.

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INTRODUCTION

Status epilepticus (SE) is a life-threatening neurological emergency defined by prolonged or recurrent seizure activity in which the patient does not regain full consciousness between episodes. Traditionally, SE was characterized by seizures lasting more than 30 minutes or a series of seizures without intervening recovery of consciousness. However, current guidelines from the Neurocritical Care Society have updated this definition to include five or more minutes of continuous clinical or electrographic seizure activity, or recurrent seizures without full recovery of consciousness in between.^[1] This updated definition reflects growing evidence that early intervention within this critical timeframe is vital to prevent irreversible neuronal injury and minimize morbidity and mortality. SE encompasses a range of subtypes with differing clinical manifestations and treatment implications. The most frequently encountered variant in pediatric populations is convulsive status epilepticus (CSE), characterized by prolonged generalized tonic-clonic seizures with impaired mental status.^[2] Other forms include non-convulsive status epilepticus (NCSE), which lacks overt motor symptoms and requires electroencephalography (EEG) for diagnosis,^[3] focal motor status epilepticus involving localized motor manifestations, and myoclonic status epilepticus, marked by repetitive, brief muscle jerks. Refractory status epilepticus (RSE) is defined by the persistence of seizures despite

administration of at least two appropriate anti-epileptic drugs (AEDs), often necessitating anesthetic agents and intensive care support.^[4]

Pediatric SE represents the most common neurological emergency among children, with reported incidence rates ranging from 7 to 40 cases per 100,000 annually.^[5] The condition demonstrates a bimodal age distribution, most notably affecting infants under one year and the elderly. It is estimated that nearly 70% of SE cases in children occur before the age of one, and 75% occur in those under three years.^[6] A male predominance has been reported consistently, possibly influenced by genetic and hormonal mechanisms.^[7]

The etiology of SE in children is heterogeneous and often age-dependent. Causes may be classified into acute symptomatic, remote symptomatic, progressive symptomatic, and cryptogenic categories.^[8] Acute symptomatic causes include central nervous

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system (CNS) infections such as meningitis and encephalitis, metabolic disturbances like hypoglycemia or hyponatremia, cerebrovascular events, traumatic brain injury, hypoxia, or drug toxicity.^[9] Febrile SE is particularly common in younger children and is frequently associated with viral illnesses.^[10] Remote symptomatic SE arises from pre-existing neurological insults such as perinatal brain injury, epilepsy, or prior stroke. Progressive causes include CNS tumors and neurodegenerative disorders, while cryptogenic SE refers to cases with no immediately identifiable etiology, often with a suspected underlying genetic or metabolic basis.^[11]

The underlying pathophysiology of SE involves a disruption in the balance between excitatory and inhibitory neuronal signals. Normally, seizure activity is self-limited through inhibitory mechanisms mediated by gamma-aminobutyric acid (GABA), the brain's chief inhibitory neurotransmitter.^[3] In SE, this balance is lost due to impaired GABAergic function or unchecked excitatory neurotransmission via glutamate. The resulting neuronal hyperactivity leads to metabolic stress, blood-brain barrier dysfunction, and ultimately, excitotoxic injury and cell death.^[4] These processes are especially detrimental in the developing pediatric brain, leading to long-term sequelae.

Experimental studies have demonstrated that sustained seizures activate inflammatory cascades, microglial responses, and apoptotic pathways, especially in the hippocampus and cortical areas. This neuroinflammation contributes to subsequent epileptogenesis and cognitive deficits. Consequently, children who suffer prolonged SE are at higher risk of developing epilepsy, intellectual disability, and behavioral disorders.^[6]

Effective SE management depends on rapid and structured treatment protocols. First-line therapy includes benzodiazepines such as lorazepam, diazepam, or midazolam, which act swiftly to enhance GABAergic inhibition.^[10] If seizures persist, second-line agents like phenytoin, levetiracetam, valproate, or phenobarbital are administered.^[6] In cases of RSE, continuous infusions of anesthetic agents such as midazolam, propofol, or pentobarbital are required for seizure control.^[4] The urgency of early intervention is emphasized by studies showing increased risks of irreversible brain damage with seizure durations beyond 30–60 minutes.^[11] Delays in the administration of effective AEDs are directly associated with poorer neurological outcomes and increased mortality.^[3]

Short-term mortality in pediatric SE ranges between 2.1% and 6%, though rates are typically higher in resource-limited settings.^[11] Long-term consequences include the development of epilepsy in up to 20% of survivors within five years, as well as variable degrees of cognitive and behavioral impairment.^[6] Prolonged seizures have also been linked to structural changes in the brain, particularly hippocampal sclerosis, which predisposes children to temporal lobe epilepsy.^[10] The neurodevelopmental impact is especially severe in children with underlying metabolic or genetic disorders.^[8]

Despite advancements in therapeutic protocols and critical

care support, SE continues to pose considerable management challenges, particularly in pediatric populations. Understanding the clinico-etiological profile of SE and its association with early outcomes is crucial for improving treatment strategies. This study aims to assess the clinical spectrum, etiologies, early outcomes, and therapeutic responses in pediatric SE, with a particular focus on the relationship between the number of AEDs required and seizure resolution. Through this research, we aim to contribute to the evidence base guiding pediatric SE management and help mitigate its associated burden on patients, families, and healthcare systems.

MATERIALS AND METHODS

This prospective, observational study was conducted over a period of 12 months, from September 24, 2023, to September 24, 2024. The study included all children aged 1 month to 18 years who presented with status epilepticus (SE) or developed SE during hospitalization in the pediatric intensive care unit. Patients were selected using convenience sampling and enrolled if they met the inclusion criteria and had no exclusions.

The inclusion criteria comprised all children aged 1 month to 18 years diagnosed with convulsive SE, either at presentation or during their hospital stay. Only those whose parents or legally authorized representatives provided informed consent were included. Children were excluded if consent was denied.

A total of 100 patients were included in the final analysis. Detailed clinical and demographic data were collected using a structured, predesigned case record form. This included presenting features, relevant history, examination findings, investigations, treatment details, and outcome measures. Particular attention was given to the etiology of SE, the number and type of anti-epileptic drugs (AEDs) used, seizure duration, need for intensive care interventions, and early outcomes such as seizure control, recovery of consciousness, and requirement of ventilatory or inotropic support.

The primary outcomes assessed were seizure resolution, neurological recovery, and short-term progression to refractory or super-refractory SE. The association between clinical parameters and outcomes was also examined. All data were compiled in Microsoft Excel 2016 and analyzed using IBM SPSS version 22. Descriptive statistics were reported as frequencies and percentages. Categorical variables were compared using the Chi-square test, with a p-value of <0.05 considered statistically significant.

The study was conducted following approval from the Institutional Ethics Committee. Written informed consent was obtained, and patient confidentiality was strictly maintained throughout the study. No additional investigations were performed for research purposes, and the study was fully funded by the investigator.

RESULTS

A total of 100 children diagnosed with status epilepticus were included in the study. The most commonly affected age group was 1–5 years (36%), followed by children <1 year and >5 years (32% each). A male predominance was evident, with boys comprising 60% of the cohort. Generalized tonic-clonic seizures were the predominant seizure type, observed in 87% of cases,

while focal seizures occurred in 13%. Nearly half of the participants (47%) had a history of seizures prior to the index episode, while 53% presented with new-onset seizures [Table 1].

Acute symptomatic etiology was slightly more common (53%) than SE in children with pre-existing epilepsy (47%). Among acute causes, CNS infections—primarily meningitis and encephalitis—accounted for 27% of cases, followed by febrile seizures (8%), metabolic disturbances (7%), and stroke (6%). Rare but important etiologies included FIRES, neurocysticercosis, poisoning, and hypertensive encephalopathy (1% each). In children with chronic epilepsy, the predominant underlying conditions included cerebral palsy (13%), hypoxic-ischemic encephalopathy (4%), and other metabolic, genetic, or immune causes.

In terms of pharmacologic management, 38% of children responded to a single anti-epileptic drug (AED), while 37% required two AEDs. Higher escalation was needed in a subset: 12% required three drugs, 6% needed four, and 7% were managed with five AEDs. Overall, seizure control within one hour was achieved in 88% of patients; 5% achieved control within 1–24 hours, and 7% required more than 24 hours. Consequently, 5% progressed to refractory status epilepticus (RSE) and 7% to super-refractory status epilepticus (SRSE).

Clinical assessment at 24 hours revealed that 72% of patients had complete recovery of consciousness. However, 25% had incomplete recovery and 3% remained unresponsive. Nearly one-third of the cohort (31%) required

ventilatory support, while 27% required inotropic support due to associated systemic instability [Table 1].

Several clinical parameters demonstrated statistically significant associations with seizure outcomes [Table 2]. Seizure duration was a strong predictor: among children with seizures lasting <15 minutes, 96% achieved control within one hour, compared to just 64% in those with seizures >30 minutes (p=0.001). The number of AEDs required also correlated with outcome—children receiving 1–2 AEDs had 100% seizure resolution, whereas none in the group requiring five AEDs achieved early control; notably, 83.3% of this group progressed to SRSE (p=0.001).

Need for ventilatory and inotropic support was significantly associated with poor seizure control. Among patients not requiring ventilation, 98.6% achieved seizure resolution within one hour, compared to 64.5% in those who were ventilated (p=0.001). Similarly, seizure resolution occurred in 96.5% of those not on inotropes, while only 70.4% of inotrope-requiring patients achieved early control (p=0.004).

Etiological analysis further revealed that children with stroke (p=0.004), FIRES (p=0.001), and genetic epilepsies such as mitochondrial disorders and neuronal ceroid lipofuscinosis (p=0.001) were significantly more likely to progress to RSE or SRSE. In contrast, children with benign epilepsies or unknown etiologies had excellent seizure control, with 100% achieving resolution within one hour (p=0.001).

Although prolonged pediatric intensive care unit (PICU) stay tended to occur in children with poorer outcomes, the association did not reach statistical significance (p=0.079).

Table 1: Demographic and Clinical Profile of Children Presenting with Status Epilepticus

Variable	Number of Patients	Percentage (%)
Age Group: <1 year	32	32.0%
Age Group: 1–5 years	36	36.0%
Age Group: >5 years	32	32.0%
Sex: Male	60	60.0%
Sex: Female	40	40.0%
Seizure Type: Generalized	87	87.0%
Seizure Type: Focal	13	13.0%
History of Seizure Present	47	47.0%
No Seizure History	53	53.0%
Seizure Control within 1 hour	88	88.0%
Seizure Control >1 hour	12	12.0%

Includes age distribution, sex, seizure type, history of seizures, and initial seizure control.

Percentages are calculated based on the total study population (n = 100).

“Generalized seizures” refer primarily to generalized tonic-

clonic seizures.

“Seizure control within 1 hour” indicates cessation of clinical seizure activity following initiation of treatment, without progression to refractory status.

Table 2: Clinical and Etiological Predictors of Early Seizure Resolution versus Progression to Refractory or Super-Refractory Status Epilepticus

Clinical Variable	Seizure Resolved within 1 hr	Progressed to RSE/SRSE	p-value
Seizure Duration <15 mins	96%	4%	0.001*
Seizure Duration >30 mins	64%	36%	0.001*
AEDs Used: 1–2	100%	0%	0.001*
AEDs Used: ≥5	0%	83.3%	0.001*
Ventilatory Support Not Needed	98.6%	1.4%	0.001*
Ventilatory Support Needed	64.5%	35.5%	0.001*
Inotropic Support Not Needed	96.5%	3.5%	0.004*
Inotropic Support Needed	70.4%	29.6%	0.004*

Etiology: Stroke	66.7%	33.3%	0.004*
Etiology: FIRES	0%	100%	0.001*
Genetic Etiology Present	0%	100%	0.001*
Benign/Unknown Etiology	100%	0%	0.001*

Includes seizure duration, number of AEDs used, need for critical care support, and underlying etiology.

“Seizure resolved within 1 hr” refers to cessation of seizures within one hour of treatment initiation using standard AED protocols.

“RSE” (Refractory Status Epilepticus) is defined as failure to respond to at least two appropriate AEDs.

“SRSE” (Super-Refractory Status Epilepticus) refers to continued or recurrent seizures 24 hours after onset of anesthetic therapy.

p-values are calculated using the Chi-square test.

*p < 0.05 = statistically significant.

FIRES: Febrile Infection-Related Epilepsy Syndrome.

DISCUSSION

Status epilepticus (SE) continues to represent one of the most challenging pediatric neurological emergencies due to its varied etiology, evolving pathophysiology, and high potential for morbidity and mortality. In the present study, SE was observed most commonly in children between 1–5 years of age (36%), followed by those <1 year and >5 years (32% each), reaffirming the age distribution noted in earlier studies by Chin et al,^[12] and Sanchez Fernandez et al.^[13] The higher vulnerability of the younger population may be attributed to a combination of factors including immature neuronal networks, increased susceptibility to infections, and underlying neurodevelopmental disorders. Male predominance (60%) was observed, similar to that reported by Das et al,^[14] Garasiya et al,^[15] and Sahu et al.^[16]

Generalized tonic-clonic seizures (GTCS) were the most frequent seizure type, accounting for 87% of cases, consistent with findings from previous Indian cohorts.^[14,17] The proportion of children with prior history of seizures (47%) was comparable to other studies, indicating that SE often presents as a decompensation of poorly controlled epilepsy in known patients.^[14,18] Acute symptomatic causes slightly outnumbered seizures in epileptic patients (53% vs. 47%), aligning with Indian literature where infectious, febrile, and metabolic causes remain common triggers.^[14,15,19]

CNS infections, notably meningitis and encephalitis, were the most frequent acute causes (27%). These findings mirror earlier data from India highlighting the persistent burden of neuroinfections in pediatric SE. 14,15 Febrile seizures (8%), metabolic disturbances (7%), and stroke (6%) were also important contributors. Notably, stroke was a significant cause of refractory SE in this study. In contrast to other series, febrile seizures were relatively less frequent, which may reflect the more severe spectrum of SE captured in tertiary referral settings. Among epilepsy-associated SE, structural abnormalities such as cerebral palsy (13%) and hypoxic-ischemic encephalopathy (4%) were commonly observed, a finding consistent with the study by Merani et al.^[19]

A small but clinically significant proportion of patients presented with rare and high-risk etiologies such as FIRES, neurocysticercosis, mitochondrial disorders, and neuronal ceroid lipofuscinosis. These patients were disproportionately represented among those with poor outcomes, including refractory and super-refractory SE. Such associations, though underreported in earlier Indian studies, are increasingly recognized in recent global literature and highlight the need for heightened clinical suspicion and early aggressive management in such cases.^[14]

Therapeutically, seizure resolution within one hour was achieved in 88% of children. This outcome is noteworthy, given that earlier studies, including those by Das et al. and Beegum et al., reported lower response rates and a higher incidence of refractory SE.^[14,18] The use of two or fewer AEDs was sufficient in 75% of cases, underscoring the importance of early and appropriate drug administration. However, children requiring five AEDs had significantly worse outcomes, with 83.3% progressing to SRSE (p=0.001), in agreement with mechanisms of pharmacoresistance described by Sanchez Fernandez et al.^[20]

The need for ventilatory (31%) and inotropic support (27%) was common and significantly associated with poor seizure control and worse outcomes (p=0.001 and p=0.004, respectively). These findings are supported by observations from Garasiya et al,^[14] and Das et al,^[14] and suggest that these requirements may serve as indirect markers of SE severity. Among those who did not require ventilatory or inotropic support, early seizure control and recovery were markedly better.

A strong association between seizure duration and outcome was evident. Children with seizures lasting less than 15 minutes had 96% resolution within one hour, whereas those with seizures longer than 30 minutes had only 64% resolution (p=0.001). This reinforces prior data from Hesdorffer et al,^[22] and others highlighting the adverse impact of prolonged seizure activity on neuronal function and treatment responsiveness.^[23] Consciousness recovery at 24 hours was complete in 72% of patients, while 28% had incomplete or no recovery, consistent with findings from Holtkamp et al. and Wasterlain et al. regarding the prognostic value of postictal sensorium.^[24,25]

Importantly, the etiological profile emerged as a key determinant of prognosis. Stroke, FIRES, and genetic disorders were strongly associated with refractory or super-refractory outcomes (p=0.004 and p=0.001), whereas children with benign epilepsy syndromes or unknown etiology generally had favorable outcomes (p=0.001). This further supports the findings of Singh et al. and Chin et al. that underline the role of underlying pathology in shaping SE trajectory and prognosis.^[12,26]

Interestingly, no significant association was observed between age group and seizure outcome (p=0.946), or between the duration of PICU stay and final outcome (p=0.079). This is in line with findings from Abend et al., suggesting that clinical and

therapeutic factors may outweigh demographic variables in determining short-term SE outcomes.^[27]

While this study provides a detailed clinic-etiological characterization of pediatric SE and highlights several predictors of early outcome, certain limitations remain. Being a single-center study, findings may not be generalizable. AED-specific outcomes were not assessed, and long-term cognitive sequelae could not be evaluated within the study period. However, the recognition of rare but impactful etiologies and the demonstration of strong outcome correlations with seizure duration, AED use, and organ support requirements are major strengths.

The study reinforces the need for early seizure termination, aggressive escalation when needed, and rapid etiological diagnosis. These strategies remain pivotal in reducing the risk of progression to refractory states and improving survival and neurological recovery in children with status epilepticus.

CONCLUSION

Status epilepticus in children presents with diverse etiologies and clinical profiles, with CNS infections and structural epilepsies being predominant causes. Early seizure termination, particularly within one hour and with fewer anti-epileptic drugs, is strongly associated with favorable outcomes. Prolonged seizure duration, need for ventilatory or inotropic support, and etiologies such as stroke, FIRES, and genetic disorders are significant predictors of poor prognosis. Timely intervention and etiological identification remain key to improving outcomes in pediatric status epilepticus.

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Conflicts of interest

There are no conflicts of interest.

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