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Hyperkalemic emergency department patients intubated with rocuronium or succinylcholine: Retrospective study of clinical outcomes

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ABSTRACT

Study objective: Emergency department (ED) clinicians often avoid succinylcholine due to concerns about potassium elevation leading to adverse events, though clinical evidence beyond case reports is limited. Rocuronium is a non-depolarizing paralytic that does not affect potassium levels. Therefore, it is perceived as safer despite causing longer paralysis than succinylcholine. This study aimed to compare adverse clinical outcomes in patients with pre-existing hyperkalemia who received either succinylcholine or rocuronium during rapid sequence intubation (RSI) in the ED.

Methods: We conducted a retrospective cohort study of all ED patients aged ≥18 years presenting between October 2015 and July 2024 with initial serum potassium >5.5 mmol/L who underwent RSI with either rocuronium or succinylcholine. Data included demographics, medical history, lab values, medication administration, hospital course, and chart-reviewed details of adverse events. The primary outcome was death within 24 hours of RSI. The secondary outcome was cardiac arrest within 1 hour of RSI.

Results: 434 patients were included in analysis: 310 were paralyzed with rocuronium and 124 with succinylcholine. There was no significant difference in 24-hour mortality (rocuronium 10.0%, succinylcholine 10.5%, p= 0.989). Cardiac arrest within 1 hour occurred in 7 cases (1.6% overall). 6 cases were in the rocuronium group (1.9%) and 1 in the succinylcholine group (0.8%, p=0.758). None of these arrests were fatal. Regression analysis showed no association between paralytic choice and 24-hour mortality (OR 0.911, 95% CI 0.414–2.00). Among succinylcholine cases, potassium level was not associated with increased 24-hour mortality (OR 1.311, 95% CI 0.359–4.780).

Conclusion: We found no statistically significant difference in clinical adverse events between succinylcholine and rocuronium in hyperkalemic ED patients. While limited by its retrospective design, this study questions the presumed clinical importance of potassium levels in paralytic selection for RSI.

1. Background

Succinylcholine and rocuronium are the most common paralytic agents used in emergency department (ED) rapid sequence intubation (RSI). It is well established that both agents (at appropriate dosages) induce paralysis rapidly to create optimal intubation conditions [1-3]. Therefore paralytic agent selection is guided by risk profile, rather than efficaciousness. Induced hyperkalemia is often cited as a concerning effect of succinylcholine [1-6].

Succinylcholine is a depolarizing agent that causes a transient increase in serum potassium of 0.3–1.0 mmol/L for a period of 10–15 min [5,6]. Specific patient populations may have acetylcholine receptor up-regulation (e.g. subacute major burns and denervation conditions) [7-10] and are thought to be at greater risk of potassium-related adverse outcomes [6,7,11]. When excluding these patients with recent major burns or conditions such as Guillan-Barré and muscular dystrophy, there still remains a great majority of cases where it is unclear if succinylcholine-induced rise in potassium leads to adverse clinical outcomes [12]. Although concern for cardiac instability from transient hyperkalemia is founded on reasonable pathophysiologic principles, we failed to find studies outside of case reports [13-23] supporting any correlation between succinylcholine and clinical instability or cardiac arrest, even in patients with pre-existing hyperkalemia.

Succinylcholine is unique in that it is rapidly cleared, resulting in a shorter duration of paralysis. This enables clinicians to assess neurological status, analgesia, and levels of sedation soon after intubation. Succinylcholine's reported adverse effects include masseter spasm, myalgia, muscarinic bradycardia, and rarely, malignant hyperthermia [4,7,24]. But the most common effect and primary topic of concern in

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the literature regarding succinylcholine has been the rise in serum potassium with the feared consequence of cardiac instability [4,5,7].

Rocuronium is a non-depolarizing paralytic. It must occupy a large proportion of receptors to induce paralysis and must dissociate from those receptors to restore muscular function, so onset and duration are dose dependent. When dosed at 1.0–1.2 mg kg^{-1} (ideal body weight) onset of paralysis is about 45 s, but this high dose results in paralysis lasting 90–120 min [1,25-29]. The prolonged duration of paralysis precludes neurologic assessments and clinical monitoring of patient sedation. This impedes clinical assessments which can be crucial in cases such as stroke, traumatic brain injury, seizure, and uncontrolled pain. Further, rocuronium has been demonstrated to put patients at increased risk of the traumatic experience of inadequate sedation and subsequent awake paralysis [30-38]. Rocuronium is not associated with cellular ion shifts or increases in serum potassium, and there are no major contraindications or cautions with its use. This imparts rocuronium with a perceived margin of safety over succinylcholine despite the risk of patient paralysis without adequate sedation.

There is a notable dearth of evidence that would suggest an increased incidence of adverse events in hyperkalemic patients who receive succinylcholine. Literature review did not identify any published literature in the last 20 years on the issue. In 2002 Schow et al. found no adverse events in their retrospective review of anesthesia patients with pre-existing hyperkalemia (≥ 5.6 mEq/L) who received succinylcholine [17]. Their comprehensive literature review only identified case reports on hyperkalemic patients receiving succinylcholine (total of 15 patients reported on). While there have been more case reports since 2002, there has been no other original research investigating succinylcholine use in hyperkalemic patients. One recent comprehensive review (Radkowski et al. 2024) [39] explores neuromuscular blocking agents and reversal agents in patients with kidney dysfunction (a population prone to hyperkalemia). When exploring succinylcholine and its effects on potassium (both in general and in cases of renal impairment), they only identify one critical literature review, also published over 20 years ago (Thapa et al. 2000) [40]. Despite this demonstrated lack of evidence, practice patterns are shifting away from succinylcholine in the ED, with rocuronium increasing in popularity [41].

Our study aims to investigate risks of adverse clinical outcomes in adult patients with pre-existing hyperkalemia who received either rocuronium or succinylcholine while undergoing RSI in the ED.

2. Methods data collection and analysis

2.1. Study design and setting

We performed a retrospective cohort study of ED patients who presented between October 2015 and July 2024. The study included patients presenting to hospitals within a single health system, which functions as a community-academic hybrid with an emergency medicine residency, level 1 trauma center, and tertiary care referral center for the region. The study was reviewed and deemed exempt by the institutional review board.

2.2. Selection of participants

Patients aged 18 years and older, who had initial serum potassium (K) > 5.5 mmol/L, and who required RSI with either rocuronium or succinylcholine were included. Patients were excluded if they did not receive a paralytic agent, if it was unclear which paralytic they received, or if the patient was intubated during cardiac arrest.

2.3. Data collection

Initial data collection included demographic data (age, gender, race, ethnicity, and weight) as well as outcomes data for the included population. We searched patient records for ICD-10 codes indicating any prior history of chronic kidney disease (CKD), dialysis-dependent end-stage renal disease (ESRD), congestive heart failure (CHF), coronary artery disease (CAD), type 1 or type 2 diabetes, upper motor neuron disease, amyotrophic lateral sclerosis, multiple sclerosis, Gordon Holmes syndrome, Guillain-Barré Syndrome, botulism, Lambert-Eaton Syndrome, Duchenne or Becker Muscular dystrophy, or burns.

For the encounter in question, ICD-10 codes were obtained to evaluate for sepsis, electrocution, crush injury, burns, diabetic ketoacidosis, and cardiac arrest (see supplemental materials for code definitions). Encounters were also queried to identify specialty service activations such as trauma.

Information regarding medications was obtained from the medication administration record (MAR), dispensing logs from automated dispensing cabinets, as well as querying ED physician and nursing documentation. Information on the following medications were collected: paralytics (rocuronium and succinylcholine), induction medications (e.g. etomidate), intravenous (IV) calcium (calcium chloride or calcium gluconate), continuous vasopressors (norepinephrine, epinephrine, vasopressin, phenylephrine, angiotensin), furosemide, sodium bicarbonate, and albuterol.

Laboratory data were collected including initial levels of potassium, serum creatinine, bicarbonate, calculated anion gap, creatinine kinase, lactate, and blood pH. Although we were unable to gather data on timing of blood draws, general protocol at our institution is to draw labs from the first point of access, and we therefore assumed that labs were drawn at the time of establishing IV access, prior to administration of IV paralytic medications. Where available, potassium and creatinine levels from prior visits (the last five available values) were pulled from records to determine baseline levels.

Patient encounters were evaluated for admission destination from the ED, hospital length of stay, discharge destination, in-hospital mortality, and 24-h mortality. We performed a standardized manual chart review on encounters meeting inclusion criteria for details of intubation and adverse events. This process utilized a standard protocol agreed upon by all team members and involved examining documentation for details of patients' hospital course and identification of any adverse events. Any patient encounter that included an ICD-10 code for cardiac arrest was reviewed to find documented information regarding circumstances of the arrest, timing of intubation in relation to cardiac arrest, as well as outcome of the resuscitation. For any patient who died within 24 h of paralytic administration, charts were reviewed for clinical details surrounding the patient's death, including any decision to limit interventions or transition to comfort measures only. Data were collected in a standardized RedCap data tool [42,43].

2.4. Outcome measures

Our primary outcome of interest was 24-h mortality following paralytic administration. Secondary outcome was cardiac arrest within 1 h of paralytic administration.

2.5. Statistical analysis

Data were analyzed with descriptive statistics and chi-squared tests utilizing the SAS software suite with statistical analysis package. For variables that were not dichotomous, chi-squared tests were run comparing the largest group to all others together to reduce degrees of freedom and increase statistical power. A multivariable logistic regression model was also used to examine association between patient characteristics and primary outcome of death within 24 h. Candidate variables were selected based on clinical relevance. Variables demonstrating quasi-complete separation were excluded. Variables included in the final model were: paralytic used, age, initial potassium level, diagnosis of sepsis, trauma activation, history of CKD, history of dialysis-dependent ESRD, history of CHF, history of type II diabetes, and IV calcium administration prior to intubation. Model fit was evaluated

using the −2 log likelihood and Akaike information criterion (AIC). Adjusted odds ratios (OR) with 95 % confidence intervals (CI) are reported. All analyses were performed using SAS software and statistical significance was defined as $p < 0.05$.

3. Results

There were 13,016 encounters for adults with hyperkalemia in the ED during this 9-year period. Of these, 447 underwent RSI with either rocuronium or succinylcholine. Thirteen encounters were excluded, leaving 434 available for evaluation. Rocuronium was used as the paralytic in 310 encounters. Succinylcholine was used in the remaining 124 encounters (See Fig. 1).

No patient had an ICD-10 code identifying prior history of upper motor neuron disease, amyotrophic lateral sclerosis, multiple sclerosis, Gordon Holmes syndrome, Guillain-Barré syndrome, botulism, Lambert-Eaton syndrome, Duchenne or Becker Muscular dystrophy, type 1 diabetes, or burn. No encounters identified diagnosis of electrocution, crush injury, or burn.

There was no statistically significant difference in demographics between groups. Almost half of the patients (46.3 %) had a prior history of CKD (49.4 % of the rocuronium group and 38.7 % of the succinylcholine group; $p = 0.133$). There were 50 patient encounters involving patients with prior history of dialysis-dependent ESRD. All 50 of these patients received rocuronium. We were able to pull records of potassium levels from previous admissions in 284 (65.4 %) encounters overall. There was no statistically significant difference when comparing prior available potassium levels between the two groups (Table 1).

Overall, mean initial potassium level on arrival was 6.3 mmol/L (SD 0.7). In the rocuronium group, average initial potassium level was 6.4 (SD 0.7); in the succinylcholine group, the average was 6.2 mmol/L (SD 0.6; $p = 0.0327$, see Table 1).

Comparison of medication administration between groups revealed a statistically significant difference in IV calcium administration prior to RSI. 29 % of the rocuronium group ($n = 90$) received IV calcium pre-RSI as compared with 4 % ($n = 5$) in the succinylcholine group ($p < 0.001$).

For the primary outcome of 24-h mortality after paralytic administration there was no statistically significant difference between groups. In the rocuronium group 10 % ($n = 31/310$) died within 24 h, and in the succinylcholine group the rate was 10.5 % ($n = 13/124$; $p = 0.989$). For the secondary outcome of cardiac arrest within 1 h of paralytic administration, rates were very low overall: seven encounters (1.6 %) in the entire cohort. None of these arrests within 1 h of RSI were fatal. Six out of the seven arrests within 1 h of RSI were in the rocuronium group (1.9 %), and one was in the succinylcholine group (0.8 %, $p = 0.758$). These data are summarized in Table 1.

There were 17 patients who presented with very high potassium levels on initial labs (K ≥ 8.0 mmol/L). Three of these patients received succinylcholine (K values 8.3, 8.6, and 8.8 mmol/L), and 14 received rocuronium (average K level 8.5 mmol/L). Only two of these patients, both of whom received rocuronium, died within 24 h of intubation. None of these patients arrested within one hour of intubation.

We ran additional analyses to control for confounding variables and statistically significant differences between groups. One additional analysis excluded patients who had dialysis-dependent ESRD (Table 2). The second additional analysis excluded patients who received IV calcium prior to RSI (Table 3). Lastly, an additional analysis was run excluding both dialysis-dependent patients and those who received IV calcium prior to RSI (Table 4). For a summary of these additional analyses, please see Fig. 2.

Groups were similar in terms of demographics, past medical history, prior average potassium level, trauma activations, and diagnosis of sepsis for encounters. With these analyses, we failed to find a statistically significant difference between groups regarding primary and secondary outcomes. These data are summarized in Tables 2–4.

We also ran a multivariable logistic regression model assessing predictors of 24-h mortality following RSI. Paralytic agent was not significantly associated with 24-h mortality (OR 0.911; 95 % CI 0.414–2.00). Increasing age per year (OR 1.035, 95 % CI 1.01–1.06) was associated with higher odds of 24-h mortality. Diagnosis of sepsis for the encounter (OR 2.779, 95 % CI 1.37–5.63) and trauma activations (OR 5.84, 95 % CI 1.87–18.2) were associated with higher odds of 24-h mortality. Serum potassium level, calcium administration prior to intubation, and other comorbidities (CKD, dialysis-dependent ESRD, type 2 diabetes, CHF) were not associated with increased or decreased 24-h mortality (Fig. 3).

A second multivariable logistic regression was performed, limited to patients who received succinylcholine. Again, we assessed for predictors of 24-h mortality after RSI. Increasing age per year (OR 1.070, 95 % CI 1.02–1.13) was associated with higher odds of 24-h mortality. Serum potassium level, calcium administration prior to intubation, diagnosis of sepsis, presentation as trauma activation, and other comorbidities (CKD, dialysis-dependent ESRD, type 2 diabetes, CHF) were not associated with increased or decreased 24-h mortality (Fig. 4).

Although we collected data on calcium administration within the first hour after RSI and continuous vasopressor use prior to RSI, these variables were excluded from the regression due to quasi-complete separation. Among patients who received succinylcholine, none of the 6 who received calcium and none of the 3 who received vasopressors died within 24 h, which led to separation during model fitting.

4. Discussion

The theoretical risk of succinylcholine-induced potassium elevation leading to clinical deterioration is grounded in sound physiologic rationale, but there is currently no evidence beyond case reports demonstrating adverse clinical outcomes. Despite this, many clinicians avoid succinylcholine in hyperkalemia or when pre-intubation potassium levels are unavailable, contributing to increased use of rocuronium in the ED. [41] Although rocuronium has been identified as a risk factor for paralysis without sedation [30-37], many ED clinicians seem to perceive the risk-benefit profile of rocuronium as more favorable [41]. We aimed to assess the clinical risk of succinylcholine use in hyperkalemic patients undergoing RSI in the ED.

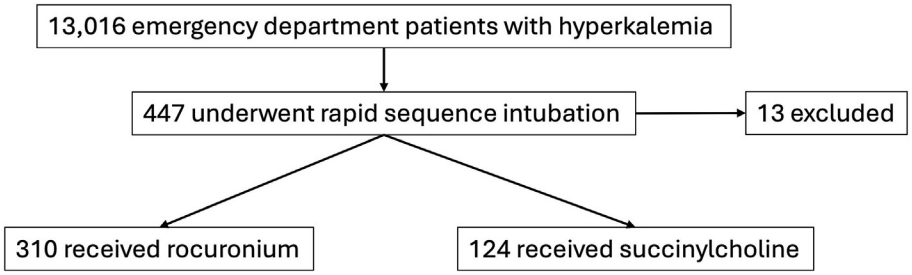

Fig. 1. Flow diagram for encounters included in the study.

Table 1
Comparison of rocuronium and succinylcholine groups' demographic data, encounter, and outcomes data.

	Total	Rocuronium	Succinylcholine	P-value
	(*N* = 434)	(*N* = 310)	(*N* = 124)	
Age				
Mean (SD)	62.5 (16.6)	62 (16.6)	63.7 (16.5)	0.631
Median [IQR]	64.5 [53, 75]	63 [52, 75]	65.5 [54.8, 75]	
Gender				
Male	220 (50.7 %)	160 (51.6 %)	60 (48.4 %)	0.832
Female	214 (49.3 %)	150 (48.4 %)	64 (51.6 %)	
Race				
White	261 (60.1 %)	181 (58.4 %)	80 (64.5 %)	*0.832
Black or African American	147 (33.9 %)	109 (35.2 %)	38 (30.6 %)	
Other Race	22 (5.1 %)	18 (5.8 %)	4 (3.2 %)	
Unavailable	4 (0.9 %)	2 (0.6 %)	2 (1.6 %)	
Ethnicity				
Hispanic or Latino	21 (4.8 %)	15 (4.8 %)	6 (4.8 %)	0.995
Non-Hispanic or Latino	400 (92.2 %)	285 (91.9 %)	115 (92.7 %)	
Unknown	13 (3.0 %)	10 (3.2 %)	3 (2.4 %)	
Weight (kg)				
Mean (SD)	87.6 (30.9)	87.1 (29.2)	88.8 (35)	0.893
Median [IQR]	83.3 [65.6, 103.4]	82.7 [66, 103.6]	84.6 [65.1, 103]	
Encounters missing data	31 (7.1 %)	20 (6.5 %)	11 (8.9 %)	
History of ESRD (dialysis dependent)	50 (11.5 %)	50 (16.1 %)	0 (0 %)	<0.001
History of CKD (not dialysis dependent)	201 (46.3 %)	153 (49.4 %)	48 (38.7 %)	0.133
History of heart failure	187 (43.1 %)	130 (41.9 %)	57 (46.0 %)	0.746
History of CAD	156 (35.9 %)	113 (36.5 %)	43 (34.7 %)	0.941
History of type II diabetes	212 (48.8 %)	161 (51.9 %)	51 (41.1 %)	0.126
Prior potassium levels mmol/L (avg up to 5 results)				
Mean (SD)	4.4 (0.5)	4.4 (0.6)	4.4 (0.4)	0.815
Median [IQR]	4.4 [4.1, 4.7]	4.4 [4.1, 4.7]	4.4 [4.1, 4.7]	
Encounters missing data	150 (34.6 %)	95 (30.6 %)	55 (44.4 %)	
Presented as trauma alert/code	21 (4.8 %)	11 (3.5 %)	10 (8.1 %)	0.141
Diagnosis of sepsis for encounter	114 (26.3 %)	87 (28.1 %)	27 (21.8 %)	0.405
Initial Serum Potassium Value (mmol/L)				
Mean (SD)	6.3 (0.7)	6.4 (0.7)	6.2 (0.6)	0.0327
Median [IQR]	6.1 [5.8, 6.7]	6.2 [5.8, 6.8]	6 [5.7, 6.5]	
Sedation Agent				
Etomidate	379 (87.3 %)	266 (85.8 %)	113 (91.1 %)	*0.322
Ketamine	41 (9.4 %)	36 (11.6 %)	5 (4.0 %)	
Propofol	7 (1.6 %)	5 (1.6 %)	2 (1.6 %)	
Lorazepam	2 (0.5 %)	2 (0.6 %)	0 (0 %)	
Midazolam	1 (0.2 %)	1 (0.3 %)	0 (0 %)	
None	4 (0.9 %)	0 (0 %)	4 (3.2 %)	
Received IV Ca2+ prior to paralytic	95 (21.9 %)	90 (29.0 %)	5 (4.0 %)	<0.001
Received IV Ca2+ within 1 h after RSI	36 (8.3 %)	30 (9.7 %)	6 (4.8 %)	0.256
Received IV Ca2+ within 24 h after RSI	126 (29.0 %)	90 (29.0 %)	36 (29.0 %)	1
Number of continuous vasopressors before RSI				
No vasopressors	396 (91.2 %)	275 (88.7 %)	121 (97.6 %)	*0.0128
1 agent	32 (7.4 %)	29 (9.4 %)	3 (2.4 %)	
2 agents	6 (1.4 %)	6 (1.9 %)	0 (0 %)	
Number of additional continuous vasopressors after RSI				
no additional agents	217 (50.0 %)	154 (49.7 %)	63 (50.8 %)	*0.978
1 additional agent	118 (27.2 %)	82 (26.5 %)	36 (29.0 %)	
2 additional agents	66 (15.2 %)	49 (15.8 %)	17 (13.7 %)	
3 additional agents	24 (5.5 %)	18 (5.8 %)	6 (4.8 %)	
4 additional agents	9 (2.1 %)	7 (2.3 %)	2 (1.6 %)	
Death within 24 h of RSI	44 (10.1 %)	31 (10.0 %)	13 (10.5 %)	0.989
Time from RSI until death (h)				
Mean (SD)	8.6 (5.9)	8.2 (5.7)	9.4 (6.4)	0.836
Median [IQR]	7.4 [3.9, 12.4]	7.2 [3.8, 11.9]	7.8 [4.5, 13.1]	
Death within 24 h of RSI (excluding those who died after transition to comfort care)	11 (2.5 %)	10 (3.2 %)	1 (0.8 %)	0.365
Time from RSI until death (h) (excluding those who died after transition to comfort care)				
Mean (SD)	8.3 (4.9)	8.6 (5.1)	5.6 (NA)	0.751
Median [IQR]	9.1 [4.3, 11.9]	9.6 [4.1, 12.2]	5.6 [5.6, 5.6]	
Arrest within 1 h of RSI	7 (1.6 %)	6 (1.9 %)	1 (0.8 %)	0.758
Required pacing after RSI	2 (0.5 %)	2 (0.6 %)	0 (0 %)	NA
Discharge location from the ED				
ICU	402 (92.6 %)	290 (93.5 %)	112 (90.3 %)	*0.245
Morgue (deceased)	26 (6.0 %)	17 (5.5 %)	9 (7.3 %)	
Discharged	5 (1.2 %)	3 (1.0 %)	2 (1.6 %)	
Stepdown	1 (0.2 %)	0 (0 %)	1 (0.8 %)	
Survived to hospital discharge	340 (78.3 %)	242 (78.1 %)	98 (79.0 %)	0.976

Abbreviations: standard deviation (SD), interquartile range (IQR), kilogram (kg), chronic kidney disease (CKD), coronary artery disease (CAD), millimoles per liter (mmol/L), average (avg), hour (h), intravenous (IV), rapid sequence intubation (RSI), emergency department (ED), intensive care unit (ICU).
* To decrease degrees of freedom of statistical tests, marked *p*-values were obtained by chi-squared analysis of the largest group tested against all others combined as a whole. For example: rates of etomidate use compared to rates of other sedatives grouped together.

Table 2
Comparison of rocuronium and succinylcholine groups when excluding all patients with dialysis dependent end-stage renal disease (ESRD), demographic data, encounter and outcomes data.

	Total	Rocuronium	Succinylcholine	P-value
	(*N* = 384)	(*N* = 260)	(N = 124)	
Age				
Mean (SD)	63.4 (16.6)	63.3 (16.7)	63.7 (16.5)	0.976
Median [IQR]	66 [54, 76]	66 [53, 76]	65.5 [54.8, 75]	
Gender				
Male	188 (49.0 %)	128 (49.2 %)	60 (48.4 %)	0.988
Female	196 (51.0 %)	132 (50.8 %)	64 (51.6 %)	
Race				
White	239 (62.2 %)	159 (61.2 %)	80 (64.5 %)	*0.916
Black or African American	120 (31.3 %)	82 (31.5 %)	38 (30.6 %)	
Other Race	25 (6.5 %)	19 (7.3 %)	6 (4.8 %)	
Ethnicity				
Hispanic or Latino	20 (5.2 %)	14 (5.4 %)	6 (4.8 %)	0.994
Non-Hispanic or Latino	352 (91.7 %)	237 (91.2 %)	115 (92.7 %)	
Unknown	12 (3.1 %)	9 (3.5 %)	3 (2.4 %)	
Weight (kg)	88.4 (31.4)	88.3 (29.7)	88.8 (35)	0.991
Mean (SD)	84 [66.2, 104.2]	83.5 [67, 104.9]	84.6 [65.1, 103]	
Median [IQR]	28 (7.3 %)	17 (6.5 %)	11 (8.9 %)	
Encounters missing data				
History of CKD (not dialysis dependent)	153 (39.8 %)	105 (40.4 %)	48 (38.7 %)	0.952
History of heart failure	157 (40.9 %)	100 (38.5 %)	57 (46.0 %)	0.376
History of CAD	134 (34.9 %)	91 (35.0 %)	43 (34.7 %)	0.998
History of type 2 diabetes	183 (47.7 %)	132 (50.8 %)	51 (41.1 %)	0.209
Prior potassium levels mmol/L (avg up to 5 results)				
Mean (SD)	4.4 (0.5)	4.4 (0.5)	4.4 (0.4)	0.992
Median [IQR]	4.4 [4.1, 4.7]	4.4 [4.1, 4.7]	4.4 [4.1, 4.7]	
Encounters missing data	143 (37.2 %)	88 (33.8 %)	55 (44.4 %)	
Presented as trauma alert/code	18 (4.7 %)	8 (3.1 %)	10 (8.1 %)	0.0966
Diagnosis of sepsis for encounter	108 (28.1 %)	81 (31.2 %)	27 (21.8 %)	0.161
Initial Serum Potassium Value (mmol/L)				
Mean (SD)	6.3 (0.7)	6.4 (0.7)	6.2 (0.6)	0.0545
Median [IQR]	6.1 [5.8, 6.7]	6.2 [5.8, 6.8]	6 [5.7, 6.5]	
Sedation Agent				
Etomidate	379 (87.3 %)	266 (85.8 %)	113 (91.1 %)	*0.288
Ketamine	41 (9.4 %)	36 (11.6 %)	5 (4.0 %)	
Propofol	7 (1.6 %)	5 (1.6 %)	2 (1.6 %)	
Lorazepam	2 (0.5 %)	2 (0.6 %)	0 (0 %)	
Midazolam	1 (0.2 %)	1 (0.3 %)	0 (0 %)	
None	4 (0.9 %)	0 (0 %)	4 (3.2 %)	
Received IV Ca2+ prior to paralytic	95 (21.9 %)	90 (29.0 %)	5 (4.0 %)	<0.001
Received IV Ca2+ within 1 h after RSI	36 (8.3 %)	30 (9.7 %)	6 (4.8 %)	0.275
Received IV Ca2+ within 24 h after RSI	126 (29.0 %)	90 (29.0 %)	36 (29.0 %)	1
Number of continuous vasopressors before RSI				
No vasopressors	396 (91.2 %)	275 (88.7 %)	121 (97.6 %)	*0.00705
1 agent	32 (7.4 %)	29 (9.4 %)	3 (2.4 %)	
2 agents	6 (1.4 %)	6 (1.9 %)	0 (0 %)	
Number of additional continuous vasopressors after RSI				
no additional agents	217 (50.0 %)	154 (49.7 %)	63 (50.8 %)	*0.736
1 additional agent	118 (27.2 %)	82 (26.5 %)	36 (29.0 %)	
2 additional agents	66 (15.2 %)	49 (15.8 %)	17 (13.7 %)	
3 additional agents	24 (5.5 %)	18 (5.8 %)	6 (4.8 %)	
4 additional agents	9 (2.1 %)	7 (2.3 %)	2 (1.6 %)	
Death within 24 h of RSI	44 (10.1 %)	31 (10.0 %)	13 (10.5 %)	0.989
Time from RSI until death (h)				
Mean (SD)	8.6 (5.9)	8.2 (5.7)	9.4 (6.4)	0.852
Median [IQR]	7.4 [3.9, 12.4]	7.2 [3.8, 11.9]	7.8 [4.5, 13.1]	
Death within 24 h of RSI (excluding those who died after transition to comfort care)	11 (2.5 %)	10 (3.2 %)	1 (0.8 %)	0.445
Time from RSI until death (h) (excluding those who died after transition to comfort care)				
Mean (SD)	8.3 (4.9)	8.6 (5.1)	5.6 (NA)	0.836
Median [IQR]	9.1 [4.3, 11.9]	9.6 [4.1, 12.2]	5.6 [5.6, 5.6]	
Arrest within 1 h of RSI	7 (1.6 %)	6 (1.9 %)	1 (0.8 %)	0.795
Required pacing after RSI	2 (0.5 %)	2 (0.6 %)	0 (0 %)	NA
Discharge location from the ED				
ICU	402 (92.6 %)	290 (93.5 %)	112 (90.3 %)	*0.350
Morgue (deceased)	26 (6.0 %)	17 (5.5 %)	9 (7.3 %)	
Discharged	5 (1.2 %)	3 (1.0 %)	2 (1.6 %)	
Stepdown	1 (0.2 %)	0 (0 %)	1 (0.8 %)	
Survived to hospital discharge	340 (78.3 %)	242 (78.1 %)	98 (79.0 %)	0.821

Abbreviations: standard deviation (SD), interquartile range (IQR), kilogram (kg), chronic kidney disease (CKD), coronary artery disease (CAD), millimoles per liter (mmol/L), average (avg), hour (h), intravenous (IV), rapid sequence intubation (RSI), emergency department (ED), intensive care unit (ICU).
*To decrease degrees of freedom of statistical tests, marked p-values were obtained by chi-squared analysis of the largest group tested against all others combined as a whole. For example: rates of etomidate use compared to rates of other sedatives grouped together.

Table 3
Comparison of rocuronium and succinylcholine groups when excluding all patients who received IV calcium prior to RSI, demographic data, encounter and outcomes data.

	Total	Rocuronium	Succinylcholine	P-value
	(*N* = 339)	(*N* = 220)	(*N* = 119)	
Age				
Mean (SD)	61.5 (17)	60.5 (17.2)	63.3 (16.6)	0.350
Median [IQR]	63 [51.5, 75]	62 [50, 74.2]	65 [54, 75]	
Gender				
Male	177 (52.2 %)	120 (54.5 %)	57 (47.9 %)	0.505
Female	162 (47.8 %)	100 (45.5 %)	62 (52.1 %)	
Race				
White	208 (61.4 %)	131 (59.6 %)	77 (64.7 %)	0.910
Black or African American	110 (32.4 %)	74 (33.6 %)	36 (30.3 %)	
Other Race	21 (6.2 %)	15 (6.8 %)	6 (5.0 %)	
Ethnicity				
Hispanic or Latino	17 (5.0 %)	11 (5.0 %)	6 (5.0 %)	0.995
Non-Hispanic or Latino	311 (91.7 %)	201 (91.4 %)	110 (92.4 %)	
Unknown	11 (3.2 %)	8 (3.6 %)	3 (2.5 %)	
Weight (kg)				
Mean (SD)	88.1 (31.3)	87.2 (29.1)	89.7 (35.3)	0.804
Median [IQR]	83.7 [65.5, 103.4]	82.3 [65.3, 103]	85 [66.2, 103.6]	
Encounters missing data	27 (8.0 %)	17 (7.7 %)	10 (8.4 %)	
History of ESRD (dialysis dependent)	36 (10.6 %)	36 (16.4 %)	0 (0 %)	<0.001
History of CKD (not dialysis dependent)	146 (43.1 %)	100 (45.5 %)	46 (38.7 %)	0.483
History of heart failure	141 (41.6 %)	87 (39.5 %)	54 (45.4 %)	0.582
History of CAD	115 (33.9 %)	74 (33.6 %)	41 (34.5 %)	0.989
History of type 2 diabetes	167 (49.3 %)	118 (53.6 %)	49 (41.2 %)	0.0909
Prior potassium levels mmol/L (avg up to 5 results)				
Mean (SD)	4.4 (0.5)	4.5 (0.5)	4.4 (0.4)	0.723
Median [IQR]	4.4 [4.1, 4.7]	4.4 [4.1, 4.7]	4.4 [4.1, 4.6]	
Encounters missing data	119 (35.1 %)	68 (30.9 %)	51 (42.9 %)	
Presented as trauma alert/code	16 (4.7 %)	6 (2.7 %)	10 (8.4 %)	0.0629
Diagnosis of sepsis for encounter	87 (25.7 %)	63 (28.6 %)	24 (20.2 %)	0.234
Initial Serum Potassium Value (mmol/L)				
Mean (SD)	6.2 (0.7)	6.3 (0.7)	6.2 (0.6)	0.226
Median [IQR]	6 [5.7, 6.6]	6.1 [5.7, 6.7]	5.9 [5.7, 6.4]	
Sedation Agent				
Etomidate	302 (89.1 %)	193 (87.7 %)	109 (91.6 %)	*0.552
Ketamine	26 (7.7 %)	21 (9.5 %)	5 (4.2 %)	
Propofol	6 (1.8 %)	4 (1.8 %)	2 (1.7 %)	
Lorazepam	2 (0.6 %)	2 (0.9 %)	0 (0 %)	
Midazolam	3 (0.9 %)	0 (0 %)	3 (2.5 %)	
None				
Received IV Ca2+ within 1 h after RSI	36 (10.6 %)	30 (13.6 %)	6 (5.0 %)	0.0495
Received IV Ca2+ within 24 h after RSI	126 (37.2 %)	90 (40.9 %)	36 (30.3 %)	0.153
Number of continuous vasopressors before RSI				
No vasopressors	317 (93.5 %)	200 (90.9 %)	117 (98.3 %)	*0.0304
1 agent	18 (5.3 %)	16 (7.3 %)	2 (1.7 %)	
2 agents	4 (1.2 %)	4 (1.8 %)	0 (0 %)	
Number of additional continuous vasopressors after RSI				
no additional agents	169 (49.9 %)	107 (48.6 %)	62 (52.1 %)	0.831
1 additional agent	93 (27.4 %)	59 (26.8 %)	34 (28.6 %)	
2 additional agents	49 (14.5 %)	33 (15.0 %)	16 (13.4 %)	
3 additional agents	19 (5.6 %)	14 (6.4 %)	5 (4.2 %)	
4 additional agents	9 (2.7 %)	7 (3.2 %)	2 (1.7 %)	
Death within 24 h of RSI	36 (10.6 %)	24 (10.9 %)	12 (10.1 %)	0.973
Time from RSI until death (h)				
Mean (SD)	8.5 (5.9)	8.4 (5.9)	8.7 (6.2)	0.986
Median [IQR]	7.4 [3.9, 12.4]	7.4 [3.8, 11.7]	6.8 [4.5, 12.6]	
Death within 24 h of RSI (excluding those who died after transition to comfort care)	9 (2.7 %)	8 (3.6 %)	1 (0.8 %)	0.364
Time from RSI until death (h) (excluding those who died after transition to comfort care)				
Mean (SD)	9 (4.8)	9.4 (5)	5.6 (NA)	0.469
Median [IQR]	10 [5.6, 12.4]	10.7 [6.4, 12.4]	5.6 [5.6, 5.6]	
Arrest within 1 h of RSI	4 (1.2 %)	3 (1.4 %)	1 (0.8 %)	1
Required pacing after RSI	1 (0.3 %)	1 (0.5 %)	0 (0 %)	NA
Discharge location from the ED				
ICU	311 (91.7 %)	203 (92.3 %)	108 (90.8 %)	*0.630
Morgue (deceased)	22 (6.5 %)	14 (6.4 %)	8 (6.7 %)	
Discharged	5 (1.5 %)	3 (1.4 %)	2 (1.7 %)	
Stepdown	1 (0.3 %)	0 (0 %)	1 (0.8 %)	
Survived to hospital discharge	262 (77.3 %)	168 (76.4 %)	94 (79.0 %)	0.859

Abbreviations: standard deviation (SD), interquartile range (IQR), kilogram (kg), chronic kidney disease (CKD), coronary artery disease (CAD), millimoles per liter (mmol/L), average (avg), hour (h), intravenous (IV), rapid sequence intubation (RSI), emergency department (ED), intensive care unit (ICU).
* To decrease degrees of freedom of statistical tests, marked p-values were obtained by chi-squared analysis of the largest group tested against all others combined as a whole. For example: rates of etomidate use compared to rates of other sedatives grouped together.

Table 4
Comparison of rocuronium and succinylcholine groups when excluding both patients who had dialysis dependent ESRD and those who received IV calcium prior to RSI, demographic data, encounter and outcomes data.

	Total	Rocuronium	Succinylcholine	P-value
	(*N* = 303)	(*N* = 184)	(N = 119)	
Age				
Mean (SD)	62.3 (17.3)	61.6 (17.7)	63.3 (16.6)	0.703
Median [IQR]	65 [52, 75]	63 [51, 76]	65 [54, 75]	
Gender				
Male	153 (50.5 %)	96 (52.2 %)	57 (47.9 %)	0.768
Female	150 (49.5 %)	88 (47.8 %)	62 (52.1 %)	
Race				
White	191 (63.0 %)	114 (62.0 %)	77 (64.7 %)	*0.937
Black or African American	92 (30.4 %)	56 (30.4 %)	36 (30.3 %)	
Other Race	20 (6.6 %)	14 (7.6 %)	6 (5.0 %)	
Ethnicity				
Hispanic or Latino	16 (5.3 %)	10 (5.4 %)	6 (5.0 %)	0.989
Non-Hispanic or Latino	277 (91.4 %)	167 (90.8 %)	110 (92.4 %)	
Unknown	10 (3.3 %)	7 (3.8 %)	3 (2.5 %)	
Weight (kg)				
Mean (SD)	88.6 (31.7)	88 (29.2)	89.7 (35.3)	0.911
Median [IQR]	84.1 [66.6, 103.9]	83.1 [67, 104.5]	85 [66.2, 103.6]	
Encounters missing data	24 (7.9 %)	14 (7.6 %)	10 (8.4 %)	
History of CKD (not dialysis dependent)	112 (37.0 %)	66 (35.9 %)	46 (38.7 %)	0.887
History of heart failure	119 (39.3 %)	65 (35.3 %)	54 (45.4 %)	0.216
History of CAD	99 (32.7 %)	58 (31.5 %)	41 (34.5 %)	0.868
History of type II diabetes	146 (48.2 %)	97 (52.7 %)	49 (41.2 %)	0.146
Prior potassium levels mmol/L (avg up to 5 results)				
Mean (SD)	4.4 (0.5)	4.4 (0.5)	4.4 (0.4)	0.941
Median [IQR]	4.3 [4.1, 4.7]	4.3 [4.1, 4.7]	4.4 [4.1, 4.6]	
Encounters missing data	114 (37.6 %)	63 (34.2 %)	51 (42.9 %)	
Presented as trauma alert/code	13 (4.3 %)	3 (1.6 %)	10 (8.4 %)	0.0177
Diagnosis of sepsis for encounter	83 (27.4 %)	59 (32.1 %)	24 (20.2 %)	0.0764
Initial Serum Potassium Value (mmol/L)				
Mean (SD)	6.2 (0.7)	6.3 (0.7)	6.2 (0.6)	0.303
Median [IQR]	6 [5.7, 6.6]	6.1 [5.7, 6.6]	5.9 [5.7, 6.4]	
Sedation Agent				
Etomidate	270 (89.1 %)	161 (87.5 %)	109 (91.6 %)	*0.535
Ketamine	24 (7.9 %)	19 (10.3 %)	5 (4.2 %)	
Propofol	4 (1.3 %)	2 (1.1 %)	2 (1.7 %)	
Lorazepam	2 (0.7 %)	2 (1.1 %)	0 (0 %)	
Midazolam	3 (1.0 %)	0 (0 %)	3 (2.5 %)	
Received IV Ca2+ within 1 h after RSI	31 (10.2 %)	25 (13.6 %)	6 (5.0 %)	0.0566
Received IV Ca2+ within 24 h after RSI	111 (36.6 %)	75 (40.8 %)	36 (30.3 %)	0.179
Number of continuous vasopressors before RSI				
No vasopressors	283 (93.4 %)	166 (90.2 %)	117 (98.3 %)	*0.0213
1 agent	16 (5.3 %)	14 (7.6 %)	2 (1.7 %)	
2 agents	4 (1.3 %)	4 (2.2 %)	0 (0 %)	
Number of additional continuous vasopressors after RSI				
no additional agents	145 (47.9 %)	83 (45.1 %)	62 (52.1 %)	*0.493
1 additional agent	88 (29.0 %)	54 (29.3 %)	34 (28.6 %)	
2 additional agents	43 (14.2 %)	27 (14.7 %)	16 (13.4 %)	
3 additional agents	18 (5.9 %)	13 (7.1 %)	5 (4.2 %)	
4 additional agents	9 (3.0 %)	7 (3.8 %)	2 (1.7 %)	
Death within 24 h of RSI	33 (10.9 %)	21 (11.4 %)	12 (10.1 %)	0.936
Time from RSI until death (h)				
Mean (SD)	8.8 (6)	8.8 (6)	8.7 (6.2)	1
Median [IQR]	7.5 [3.9, 12.4]	7.5 [3.9, 12.4]	6.8 [4.5, 12.6]	
Death within 24 h of RSI (excluding those who died after transition to comfort care)	7 (2.3 %)	6 (3.3 %)	1 (0.8 %)	0.424
Time from RSI until death (h) (excluding those who died after transition to comfort care)				
Mean (SD)	9.8 (4.7)	10.5 (4.7)	5.6 (NA)	0.610
Median [IQR]	11.4 [6.5, 12.4]	11.9 [8.5, 12.4]	5.6 [5.6, 5.6]	
Arrest within 1 h of RSI	4 (1.3 %)	3 (1.6 %)	1 (0.8 %)	1
Required pacing after RSI	1 (0.3 %)	1 (0.5 %)	0 (0 %)	NA
Discharge location from the ED				
ICU	277 (91.4 %)	169 (91.8 %)	108 (90.8 %)	*0.740
Morgue (deceased)	20 (6.6 %)	12 (6.5 %)	8 (6.7 %)	
Discharged	5 (1.7 %)	3 (1.6 %)	2 (1.7 %)	
Stepdown	1 (0.3 %)	0 (0 %)	1 (0.8 %)	
Survived to hospital discharge	230 (75.9 %)	136 (73.9 %)	94 (79.0 %)	0.601

Abbreviations: standard deviation (SD), interquartile range (IQR), kilogram (kg), chronic kidney disease (CKD), coronary artery disease (CAD), millimoles per liter (mmol/L), average (avg), hour (h), intravenous (IV), rapid sequence intubation (RSI), emergency department (ED), intensive care unit (ICU).
* To decrease degrees of freedom of statistical tests, marked p-values were obtained by chi-squared analysis of the largest group tested against all others combined as a whole. For example: rates of etomidate use compared to rates of other sedatives grouped together.

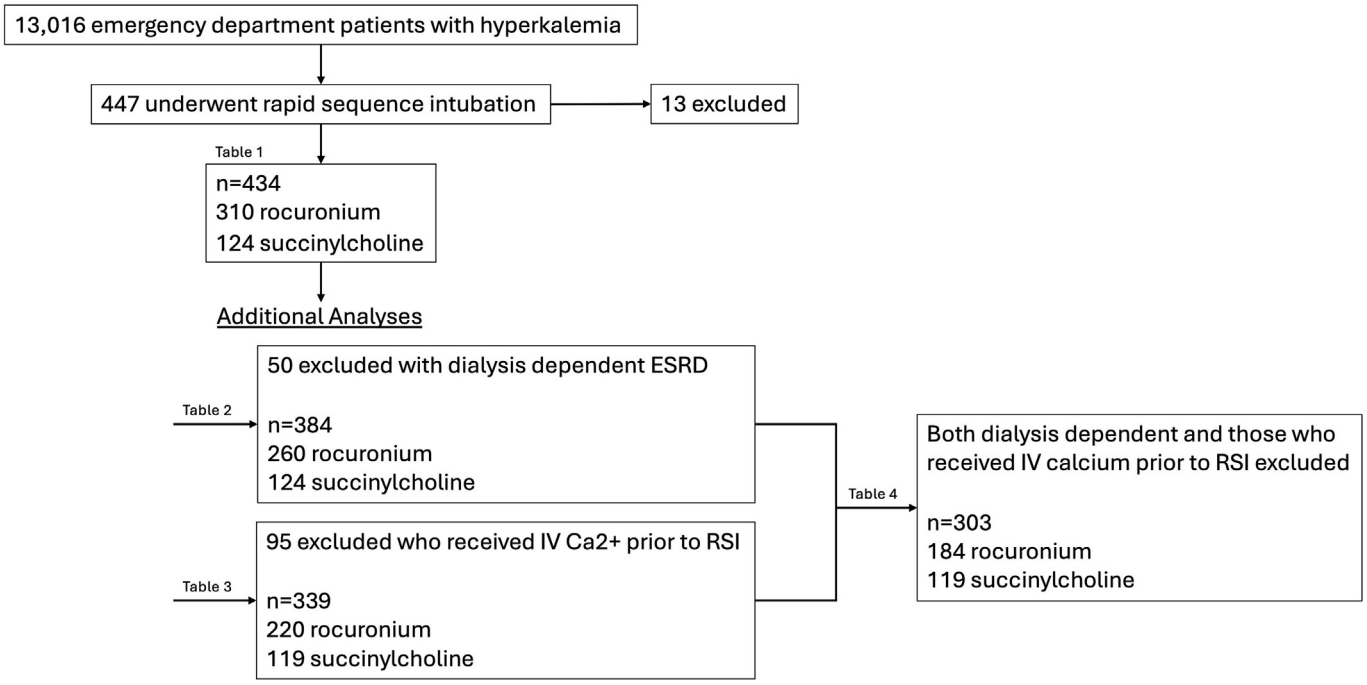

Fig. 2. Flow diagram for encounters included in the study, including details on additional analyses with different exclusion criteria.

In this retrospective study, we found that succinylcholine administration in patients with hyperkalemia did not result in increased 24-h mortality compared with patients who received rocuronium. Succinylcholine and rocuronium both had very low rates of peri-intubation cardiac arrest, and we failed to find any additional risk with succinylcholine. While the median potassium level was higher in the rocuronium group statistically (6.4 vs 6.2), this difference is likely not clinically significant. Further, linear regression analysis did not find an association between higher potassium levels and 24-h mortality in the entire cohort, or in the succinylcholine cohort alone.

This analysis is limited by its retrospective nature and is subject to bias from unrecognized confounders. Specific groups may not have been represented or randomly distributed adequately to allow generalization of results to that population. For example, there was clear selection bias towards rocuronium in dialysis-dependent ESRD patients. We are unable to comment on succinylcholine use in this population due to this discrepancy.

There was no reliable way to gauge rates of first-pass successful intubation in each group. Generally, rates of first-pass success have been demonstrated to be similar whether rocuronium or succinylcholine is

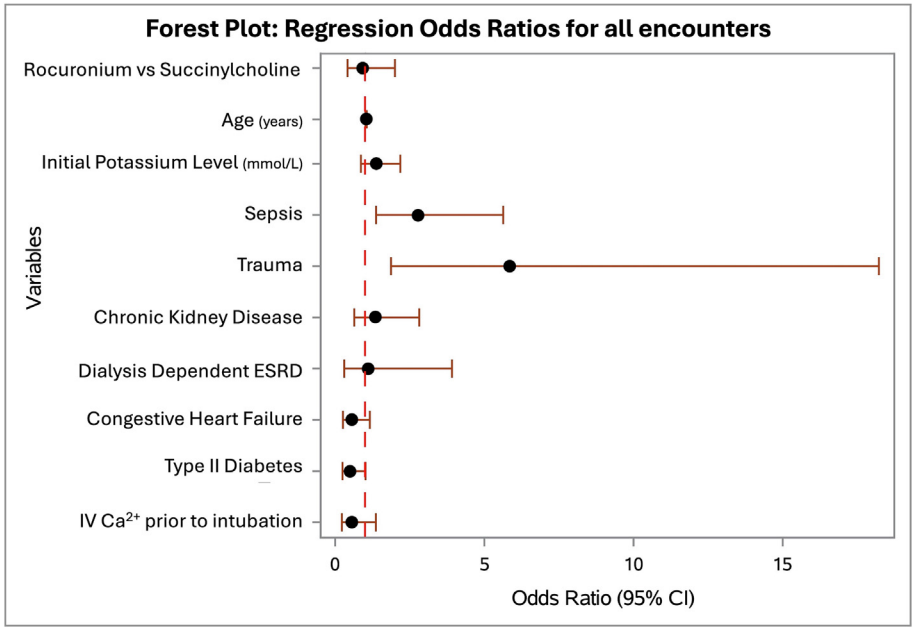

Fig. 3. Forest plot of odds ratios for the primary outcome of death within 24 h across all encounters.
Abbreviations: millimoles per liter (mmol/L), end-stage renal disease (ESRD), intravenous calcium (IV Ca2+).

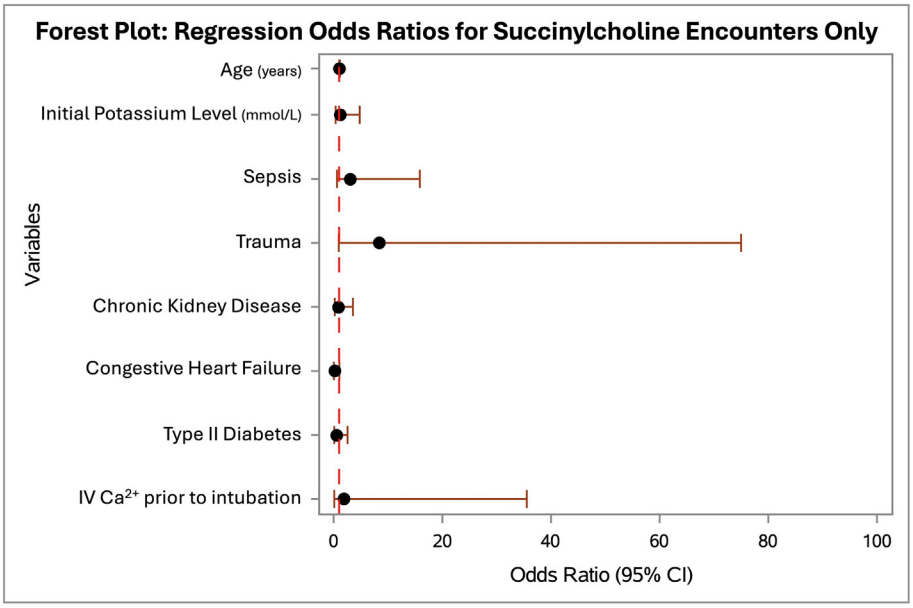

Fig. 4. Forest plot of odds ratios for the primary outcome of death within 24 h for encounters in the succinylcholine group.
Abbreviations: millimoles per liter (mmol/L), intravenous calcium (IV Ca2+).

used for paralysis [1-3], but if there had been a discrepancy in our population, it could confound outcomes, particularly secondary outcome of cardiac arrest. Recent literature fails to find correlation with first-pass success and mortality vs survival [44,45], but there is evidence to suggest that patients who desaturate or become hypotensive have higher rates of peri-intubation cardiac arrest [46-48]. There was no reliable way for us to gather information on peri-intubation desaturation events or hypotensive events, although we did investigate vasopressor use as a proxy for hypotension.

We were unable to pull data that would reliably tell us whether lab results would have been available to clinicians prior to intubation and so we are also unable to know whether clinicians were aware of potassium levels prior to choosing a paralytic agent.

We could not determine if clinicians were aware of electrocardiogram or monitor waveform changes prior to intubation. QRS prolongation, junctional rhythms, and bradycardia have been used as indicators of clinically significant hyperkalemia [49]. More patients in the rocuronium group received IV calcium pre-RSI which may reflect clinicians' observation of waveform changes, potentially influencing both calcium administration and choice of paralytic. Although pre-treatment with calcium might be expected to benefit the rocuronium group by mitigating hyperkalemia-related complications, it did not translate into a clear clinical advantage regarding this study's outcomes of interest. Additional analysis excluding patients pre-treated with IV calcium did not alter our findings. Additionally, IV calcium administration prior to RSI was not associated with decreased mortality in the regression analysis.

It is possible that harms associated with succinylcholine lead only to hemodynamic compromise without progression to cardiac arrest or death. Continuous vasopressor use in the peri-intubation period was therefore tracked across all cases. The proportion of patients requiring additional vasopressors after intubation was similar between groups, suggesting that neither agent was associated with increased hemodynamic compromise.

In this cohort, succinylcholine use was not associated with increased risk of adverse outcomes. This suggests that potassium shifts may be less clinically significant than traditionally feared. These results should be interpreted with caution and do not argue for indiscriminate succinylcholine use. As with all medical decisions, paralytic choice in ED RSI should continue to balance risks and benefits of available agents in each case.

While rocuronium maintains a robust safety profile, prolonged duration of paralysis is a significant feature that must be considered. Several studies have observed rocuronium's association with delays in initiation of post-intubation sedation compared with succinylcholine [30-36]. Compound this with the absence of reliable sedation and analgesia monitoring in many EDs, and there is significant concern for awake paralysis. Several studies have validated this harm, describing a concerning number of patients who are able to provide verifiable details of their treatment while paralyzed [30]. One meta-analysis reported overall incidence of awake paralysis as 12.3 %, with individual reported incidences ranging from 3 to 40 % [37]. Schuller et al. described anesthesiologists who underwent voluntary awake neuromuscular blockade. Despite their airway expertise, optimized ventilator settings, and understanding that they were in minimal danger, many shared traumatizing experiences [38]. ED patients, particularly those in pain, significant respiratory distress, or having ongoing seizure activity may fail to receive appropriate treatment escalation when receiving long acting neuromuscular blockade. Additionally, in patients with shock where sedatives can worsen hypotension, shorter duration of paralysis can allow clinical examination to guide titration to the minimum dose for effective sedation. Given our findings and rocuronium's prolonged neuromuscular blockade, the relative advantages of succinylcholine deserve further consideration.

5. Conclusions

In this study, we failed to find an increase in adverse events associated with succinylcholine in hyperkalemic patients undergoing ED RSI when compared to rocuronium. While the retrospective nature of this study precludes definitive conclusions, it calls into question the clinical significance of potassium values (known or unknown) on paralytic selection in the emergency department.

Potential future inquiries should include studies in larger, multicenter cohorts and specific disease states. Although prospective studies may still be infeasible, more homogeneous or carefully controlled comparison groups could enhance our understanding. Such work may help better characterize clinical outcomes among patients receiving rocuronium or succinylcholine and inform evidence-based practice.

Authors contributions

All authors contributed significantly to the development of this manuscript. Justin C. Stowens had full access to all data and takes responsibility for the integrity of the data and the accuracy of the analysis. He also contributed to study design, data acquisition, interpretation, and manuscript revision. Patricia E. Simmer contributed to study design, data acquisition, analysis, interpretation, creation of tables and figures, and manuscript writing. Michael Perza contributed to study design, data acquisition, interpretation, and manuscript writing. Dan Cho contributed to study design, data acquisition, interpretation, and manuscript revision. Elaine Boustila contributed to data acquisition and manuscript revision.

CRediT authorship contribution statement

Patricia E. Simmer: Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Michael Perza:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Data curation, Conceptualization. **Young D. Cho:** Writing – review & editing, Investigation, Data curation, Conceptualization. **Elaine Boustila:** Writing – review & editing, Data curation. **Justin C. Stowens:** Writing – review & editing, Supervision, Investigation, Data curation.

Ethical approval

Study was reviewed by Christiana Care's Institutional Review Board (IRB00000479) and deemed exempt (CCC-40071).

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None reported.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ajem.2025.11.030.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request. Access may be subject to institutional or ethical restrictions.

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