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The Limits of Succinylcholine for Critically Ill Patients

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BACKGROUND: Urgent tracheal intubations are common in intensive care units (ICU), and succinylcholine is one of the first-line neuromuscular blocking drugs used in these situations. Critically ill patients could be at high risk of hyperkalemia after receiving succinylcholine because one or more etiologic factors of nicotinic receptor upregulation can be present, but there are few data on its real risk. Our objectives in this study were to determine the factors associated with arterial potassium increase (ΔK) and to assess the occurrence of acute hyperkalemia ≥6.5 mmol/L after succinylcholine injection for intubation in the ICU.

METHODS: In a prospective, observational study, all critically ill patients intubated with succinylcholine in an ICU were screened. Only intubations with arterial blood gases and potassium measurements before and after (K_{after}) a succinylcholine injection were studied.

RESULTS: During 18 months, 131 critically ill patients were intubated after receiving succinylcholine with arterial potassium before and after intubation (K_{after}) for a total of 153 intubations. After multivariate analysis, the only factor associated with ΔK was the length of ICU stay before intubation ($\rho = 0.561$, $P < 0.001$). The factors associated with K_{after} ≥6.5 mmol/L ($n = 11$) were the length of ICU stay ($P < 0.001$) and the presence of acute cerebral pathology ($P = 0.047$). The threshold of 16 days was found highly predictive of acute hyperkalemia ≥6.5 with 37% (95% confidence interval: 19%–58%) of K_{after} ≥6.5 after the 16th day compared with only 1% (95% confidence interval: 0%–4%) of K_{after} ≥6.5 when succinylcholine was injected during the first 16 days.

CONCLUSIONS: This study shows that the risk of ΔK after succinylcholine injection is strongly associated with the length of ICU stay. The risk of acute hyperkalemia ≥6.5 mmol/L is highly significant after 16 days. (Anesth Analg 2012;115:873–9)

Succinylcholine is one of the first-line neuromuscular blocking drugs used for urgent tracheal intubation of critically ill patients in the intensive care unit (ICU).[1–3] The advantages of succinylcholine are well demonstrated,[1–7] but the major deleterious side effect is acute hyperkalemia.[8–10] The interaction between succinylcholine and the muscle's nicotinic receptors induces skeletal muscle cell depolarization with an efflux of intracellular potassium followed by neuromuscular blockage. The muscular depolarization usually induces a mean 0.5 to 1 mmol/L increase of plasmatic potassium with a peak increase at 3 to 4 minutes without clinical consequences.[9,11,12] Nevertheless, clinical reports of acute hyperkalemia have been described with cardiac arrhythmia and sometimes death.[10] Acute hyperkalemia after succinylcholine administration can be induced by rhabdomyolysis (in case of congenital myopathy) or most often by an excessive efflux of potassium due to upregulation of cholinergic receptors.[8–10] Known risk factors of receptor upregulation are anatomical denervation, prolonged administration of neuromuscular blocking drugs, burn injury, and prolonged immobilization. However, there are only experimental studies, burn victim studies, or case reports.[8–10] Although upregulation occurs after denervation or immobilization, delay of the occurrence of acute hyperkalemia is not clearly defined.[13,14]

Critically ill patients could be at high risk of hyperkalemia after succinylcholine injection because one or more etiologic factors of nicotinic receptor upregulation can be present. However, factors associated with hyperkalemia after succinylcholine injection in the ICU have been poorly investigated and its contraindications have been debated.[1–3] Beyond ICU case reports and burn victim studies,[15,16] only 1 limited ($n = 23$) clinical observational study has been published investigating the risk of hyperkalemia after succinylcholine injection in the ICU.[17] After univariate analysis, the authors found a correlation between potassium increase (ΔK) and the length of ICU stay.[17]

The objectives of this prospective, observational study were to determine the etiologic factors associated with arterial ΔK and to analyze the occurrence of hyperkalemia ≥6.5 mmol/L after succinylcholine injection in the ICU.

METHODS

Patients and Study Design

This prospective, observational study of current care was performed in the surgical ICU of Bicêtre University Hospital from September 2007 through February 2009. This hospital is a trauma center and the surgical ICU (22 beds) is in

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charge of all general surgery, polytrauma, and neurosurgery patients. The study design was approved by the IRB of GHU Nord, Paris, France (No. IRB 00006477). As recommended, patients and/or relatives were informed. The requirement for written informed consent was waived by the IRB.

All critically ill patients tracheally intubated in emergency situations with succinylcholine were included. Some patients had several intubations at different times during ICU hospitalization. In this current care study, the choice to use succinylcholine and a hypnotic (thiopental, propofol, etomidate, or ketamine) was left to the physician anesthesiologist in charge. At the time of the study, no other neuromuscular blocking drug was recommended for this indication.[1–3] Some contraindications of succinylcholine use in the ICU have been discussed based on the risk of lethal hyperkalemia.[1–3] The usual contraindications of succinylcholine are complete spinal cord injury >48 hours (para- or quadriplegia), hypersensitivity to succinylcholine, burns, and baseline potassium >5.5 mmol/L.[1–3] Of course, these contraindications were noninclusion criteria in our observational study. In our unit, in case of other pathologic states, succinylcholine could or could not be used. The succinylcholine used was Celocurine® (Orion Pharma, Espoo, Finland) 50 mg/mL (suxamethonium chloride and excipients: succinic acid, sodium hydroxide, perfusion water), diluted at 10 mg/mL, and administered by IV bolus.

Arterial Blood Gas and Arterial Potassium

The samples of arterial blood gases before and after intubation were immediately analyzed in the unit (Radiometer® ABL800 FLEX Analyzer; Radiometer, Copenhagen, Denmark) with measurements of pH, partial pressures of CO_2 ($Paco_2$, mm Hg) and O_2 (Pao_2, mm Hg), calculation of serum bicarbonate (mmol/L), and measurements of plasmatic arterial potassium concentration by potentiometry (mmol/L). Arterial blood gas specimens systematically sampled in our ICU after intubation were taken sooner than usual: between 3 and 5 minutes after succinylcholine administration to coincide with the peak of the ΔK.[9,12,18–20] The times between the first blood gas and succinylcholine administration, and between succinylcholine administration and the second blood gas were noted (minutes).

The ΔK, mmol/L, arterial potassium after succinylcholine injection minus arterial potassium before succinylcholine injection, was calculated and analyzed as a continuous variable. It has been shown that ΔK is correlated with the increase of cholinergic receptors and the risk of cardiac arrhythmia.[21]

Because there is the risk of cardiac arrhythmia with electrocardiographic changes above 6.5 mmol/L,[22] acute hyperkalemia ≥6.5 mmol/L after succinylcholine injection (K_{after} ≥6.5) was also recorded and analyzed.

The exclusion criteria were the absence of primary outcome such as arterial potassium before intubation or arterial potassium >5 minutes after succinylcholine administration making the analysis impossible.

Data Collection

All patients were monitored with electrocardiogram, oxygen saturation, and noninvasive or invasive arterial blood pressure. During intubation, complications such as arrhythmia, clinical anaphylactoid reaction (collapse and rash), and difficult intubation (>2 attempts) were recorded. Succinylcholine and hypnotic doses (mg/kg) were recorded. Patients' baseline characteristics were documented, including age, sex, weight, Simplified Acute Physiology Score (SAPS) II at admission, and medical history (neurologic, psychiatric, and peripheral vascular disease, diabetes, chronic renal failure, chronic corticotherapy, and congenital muscular dystrophies). All acute pathologies present on the day of inclusion were also noted such as polytrauma, cerebral pathology (subarachnoid hemorrhage, stroke, traumatic brain injury, brain tumor) or medullar pathology (traumatic or tumor), and severe sepsis or septic shock.[23] From ICU admission to tracheal intubation, use of the following medications during intensive care were recorded: succinylcholine during a previous intubation, prolonged infusion of neuroleptic drug, treatment with corticosteroids, or nondepolarizing neuromuscular blocking drug for >24 hours. We recorded the presence or absence of motor deficit before intubation (defined with clinical testing ≤3/5), its origin (cerebral, peripheral, or spinal cord injuries, defined by clinical testing and imagery), and its duration (more or less than 48 hours).[9] Finally, we quantified the length of ICU stay before intubation (days).

Statistical Analysis

In the descriptive analysis, continuous variables were described by median (interquartile range) and the categorical variables by percentage (95% confidence interval).

ΔK was analyzed as a continuous variable. Univariate comparison was performed with Spearman correlation (ρ) and Mann-Whitney tests based on statistical conditions. Multivariate analysis was performed by linear multivariate regression (least squares method) to identify independent etiologic factors associated with ΔK.

Comparison between the K_{after} ≥6.5 group and K_{after} <6.5 group was performed using univariate comparison with Mann-Whitney test for continuous variables and bilateral Fisher exact test for categorical variables. Multivariate analysis was performed by nominal logistic regression to identify independent etiologic factors associated with K_{after} ≥6.5. Receiver operating characteristic (ROC) curve was constructed to identify the optimal cutoff value for K_{after} ≥6.5 association.

Statistical analysis was performed by a statistician per protocol and on total population (included and excluded) in intention-to-treat. JMP 7™ software from SAS (Cary, NC) was used for data analysis. A P value <0.05 was considered statistically significant.

RESULTS

Descriptive Analysis

During 18 months, 195 critically ill patients were tracheally intubated using succinylcholine for a total of 218 intubations. One patient was not included because of a contraindication to succinylcholine (spinal cord injury with paraplegia >48 hours). Sixty-four (29%) intubations were excluded: 62 intubations because the primary outcome (arterial potassium) was not measured and 2 intubations from 1 outlier because of iterative admissions and reintubations.

Finally, 131 critically ill patients with median SAPS II at 40 (28–51) were enrolled for a total of 153 intubations analyzed per protocol. Patients' and intubations' characteristics are reported in Tables 1 and 2.

No clinical anaphylactoid reaction was noted. One case of difficult intubation with succinylcholine was reported in a polytrauma patient.

Table 1. Characteristics of the 131 Patients Included for a Total of 153 Intubations

Patient characteristics (*n* = 131 patients)	
Age in years, median (IQR)	62 (43–78)
Sex, *n* (% [CI]) men	94 (72% [63–79])
Medical history, *n* (% [CI])	
Neurologic	28 (21% [15–29])
Psychiatric	24 (18% [12–26])
Diabetes	22 (17% [11–24])
Chronic renal failure	14 (11% [6–17])
Chronic corticotherapy	10 (8% [4–14])
Peripheral vascular disease	6 (5% [2–10])
Congenital muscular dystrophies	0 (0%)
SAPS II at admission, median (IQR)	40 (28–51)
Acute pathology at inclusion,[a] *n* (% [CI])	
Cerebral pathology	53 (40% [32–49])
Polytraumatism	46 (35% [27–44])
Severe sepsis or septic shock	45 (34% [26–43])
Medullar pathology	14 (11% [6–17])

Qualitative variables are expressed in number of cases (percentage [confidence interval]). Quantitative variables are expressed in median (interquartile range).
IQR = interquartile range; CI = confidence interval; SAPS = Simplified Acute Physiology Score.
[a] A patient could have several acute pathologies at inclusion.

Table 2. Characteristics of the 153 Intubations

Intubation characteristics (*n* = 153 intubations)	
Length of intensive care unit stay in days, median (IQR)	4 (1–10)
Motor deficit, *n* (% [CI])	33 (22% [16–29])
Cerebral origin	21 (14% [9–21])
Spinal cord injury	11 (7% [4–12])
Peripheral origin	1 (0.7% [0–4])
Motor deficit >48 h, *n* (% [CI])	25 (16% [11–23])
Hypnotic used for intubation, *n* (% [CI])	
Etomidate	134 (88% [81–92])
Thiopental	10 (7% [4–12])
Propofol	5 (3% [1–7])
Ketamine	4 (3% [1–7])
Medications used from admission to the day of inclusion, *n* (% [CI])	
Succinylcholine	89 (58% [50–66])
Corticosteroids	16 (10% [7–16])
Nondepolarizing neuromuscular blocking drug	14 (9% [6–15])
Neuroleptic	13 (8% [5–14])

Qualitative variables are expressed in number of cases (percentage [confidence interval]). Quantitative variables are expressed in median (interquartile range).
IQR = interquartile range; CI = confidence interval.

Arterial blood gases and potassium measurements were performed before succinylcholine injection in a median time of 5.0 minutes (3.5–20 minutes) and 3.5 minutes (3.5–3.6 minutes), respectively, after succinylcholine injection (Table 3). The median dose of succinylcholine was 1.0 mg/kg (1–1.1 mg/kg).

Factors Associated with Arterial ΔK

The median ΔK was 0.4 mmol/L (0–0.7 mmol/L) (Table 3). After univariate analysis, there was no correlation between ΔK and age, weight, medical history, SAPS II, polytrauma, acute medullar pathology, severe sepsis or septic shock, neuroleptic and corticosteroid treatments, ΔpH, and baseline potassium (K_{before}). The etiologic factors statistically associated with ΔK were the length of ICU stay ($P < 0.001$, Fig. 1), acute cerebral pathology ($P = 0.005$), previous use of succinylcholine ($P < 0.001$) and nondepolarizing neuromuscular blocking drug during current hospitalization ($P = 0.005$). Presence of motor deficit was not associated with ΔK ($P = 0.076$) but motor deficit >48 hours was ($P = 0.001$). If we analyzed ΔK between the different origins of motor deficit, the median ΔK in patients with cerebral motor deficits (0.7 mmol/L [0.25–2 mmol/L]; $n = 21$) was significantly higher than the median ΔK of the patients with motor deficits from spinal cord or peripheral injuries (0.35 mmol/L [0.01–0.78 mmol/L]; $n = 12$) and the patients with no motor deficits (0.3 mmol/L [0–0.6 mmol/L]; $n = 120$) ($P = 0.042$).

After multivariate analysis, the only factor significantly associated with ΔK was the length of ICU stay before intubation ($P < 0.001$, Table 4). Acute cerebral pathology

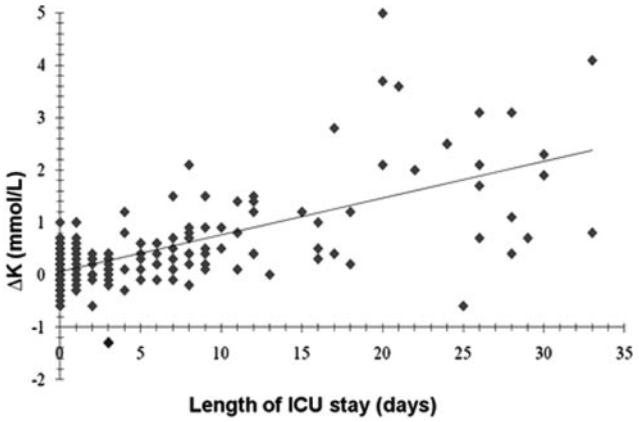

Figure 1. Correlation between potassium increase (ΔK) and length of intensive care unit (ICU) stay ($\rho = 0.561$, $P < 0.001$) (Spearman correlation) in 153 intubations.

Table 3. Arterial Blood Gases and Arterial Potassium Before and After Succinylcholine Injection in the 153 Intubations

n = 153	Before succinylcholine	After succinylcholine	Median difference Δ
pH	7.37 (7.28–7.42)	7.29 (7.22–7.34)	− 0.08 (−0.12 to −0.01)
$Paco_2$ (mm Hg)	42 (36–51)	53 (45–65)	11 (2–17)
Pao_2 (mm Hg)	103 (70–157)	155 (105–173)	52 (35–66)
HCO_3^- (mmol/L)	24 (21–27)	25 (22–28)	0 (0–0)
Sodium (mmol/L)	139 (135–141)	138 (134–141)	1 (0–1)
Potassium (mmol/L)	4.0 (3.6–4.3)	4.3 (3.8–5)	0.4 (0–0.7)

Quantitative variables are expressed in median (interquartile range).

Table 4. Multivariate Analysis of Factors Associated with Potassium Increase After Succinylcholine (ΔK) in the 153 Intubations

Factors in multivariate analysis	*P* value
Length of intensive care unit stay	<0.001*
Acute cerebral pathology	0.197
Succinylcholine preceding use	0.375
Nondepolarizing neuromuscular blocking drug preceding use	0.217
Motor deficit >48 h	0.792

Analysis by multiple linear regression (least squares method).
* $P < 0.05$.

($P = 0.102$), previous succinylcholine use ($P = 0.418$) or nondepolarizing neuromuscular blocking drug use ($P = 0.129$) during current hospitalization, and motor deficit >48 hours ($P = 0.741$) were not significantly associated with ΔK in multivariate analysis.

Acute Hyperkalemia ≥6.5 mmol/L and Associated Factors

Eleven cases of K_{after} ≥6.5 (7% [95% confidence interval {CI}: 4%–12%]) were observed, with 2 cardiac arrhythmias (ventricular tachycardia) with favorable evolution after calcium injection. The 9 other cases were asymptomatic.

Univariate comparison between groups with K_{after} ≥6.5 ($n = 11$) and groups with K_{after} <6.5 ($n = 142$) showed a significantly higher proportion of acute cerebral pathology (82% vs 37%, $P = 0.008$) and preceding succinylcholine use (91% vs 56%, $P = 0.026$) in the K_{after} ≥6.5 group. The length of ICU stay was also longer in the K_{after} ≥6.5 group (21 [20–26] vs 3 [0–8] ICU days, $P < 0.001$). No proportion difference was found for motor deficit ($P = 0.253$) or motor deficit >48 hours ($P = 0.082$). Hyperkalemia ≥6.5 mmol/L was not related to K_{before} ($P = 0.062$) or ΔpH ($P = 0.116$).

After multivariate analysis, the factors associated with K_{after} ≥6.5 mmol/L were length of ICU stay ($P < 0.001$) and the presence of acute cerebral pathology ($P = 0.047$).

After analysis of the ROC curve, there was a strong interaction between length of ICU stay and K_{after} ≥6.5 (area under the curve: 0.917 ± 0.058) (Fig. 2). A threshold of a 16-day stay in the ICU was found very predictive of K_{after} ≥6.5 mmol/L after succinylcholine injection with 90.9% (95% CI: 58.7%–98.5%) sensitivity and 90.1% (95% CI: 84%–94.5%) specificity. For intubations before a 16-day ICU stay, 1 of 126 (1% [95% CI: 0%–4%]) had a K_{after} ≥6.5 (with $K_{after} = 6.8$ mmol/L) and the median ΔK was 0.25 mmol/L (0–0.6 mmol/L). For intubations after a 16-day ICU stay, 10 of 27 (37% [95% CI: 19%–58%]) had a K_{after} ≥6.5 and the median ΔK was 1.9 mmol/L (0.7–2.8 mmol/L).

Analysis of Intention-to-Treat

Because of the large number of patients who did not meet the inclusion criterion (such as arterial potassium sample), we ensured that the main results remained valid in the extreme case of lack of hyperkaliemia in the excluded patients. Analysis of the total population in intention-to-treat (included and excluded) found that the included patients were older (median 62 vs 55 years, $P = 0.005$), had less polytrauma (34% vs 55%, $P = 0.004$), and longer ICU stay before intubation (median 4 vs 0 days, $P < 0.001$).

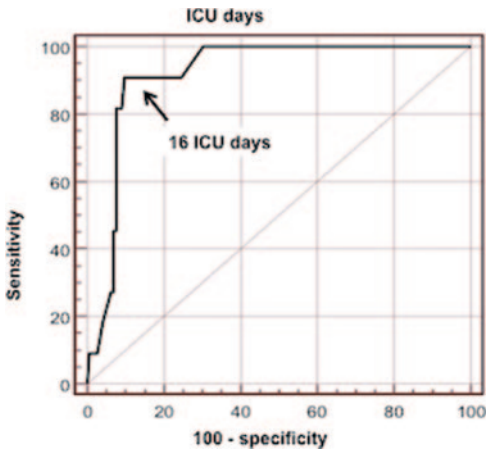

Figure 2. Receiver operating characteristic curve between intensive care unit (ICU) days and hyperkalemia ≥6.5 mmol/L risk in 153 intubations. A threshold of a 16-day stay in the ICU was found predictive of hyperkalemia after succinylcholine injection with 90.9% (95% confidence interval [CI]: 58.7%–98.5%) sensitivity and 90.1% (95% CI: 84%–94.5%) specificity (area under the curve: 0.917 ± 0.058).

Considering the extreme hypothesis that none of the excluded intubations had K_{after} ≥6.5 after succinylcholine, only the length of ICU stay was significantly associated with K_{after} ≥6.5 ($P = 0.006$), in multivariate analysis (logistic regression). The risk ratio of hyperkalemia ≥6.5 mmol/L decreased from 7.4% to 5.1%. Nevertheless, the length of ICU stay was significantly predictive of hyperkalemia ≥6.5.

DISCUSSION

In this observational study of 153 intubations using succinylcholine, the only factor associated with ΔK after multivariate analysis was the length of ICU stay before intubation ($\rho = 0.561$, $P < 0.001$). The threshold of 16 days was found highly predictive of hyperkalemia ≥6.5 with 37% (95% CI: 19%–58%) of K_{after} ≥6.5 after the 16th day compared with only 1% (95% CI: 0%–4%) of K_{after} ≥6.5 when succinylcholine was injected during the first 16 days.

Succinylcholine is one of the first-line neuromuscular blocking drugs used for urgent intubation of critically ill patients but contraindications are unclear and have been debated.[1–3,9,10] To our knowledge, this is the largest study available on hyperkalemia induced by succinylcholine in the ICU. The samples of arterial potassium were taken 5.0 minutes (3.5–20 minutes) before succinylcholine injection and 3.5 minutes (3.5–3.6 minutes) after, coinciding with the peak of acute hyperkalemia reported in the literature (between 2 and 4 minutes).[10,12,18–20] This ΔK was only induced by succinylcholine because no correlation was found between ΔK and ΔpH ($P = 0.114$) excluding the role of acidosis.[24]

After succinylcholine injection, the muscular depolarization usually induces a mean 0.5 to 1 mmol/L ΔK by efflux to cholinergic receptors without clinical consequences[11]; however, clinical reports of acute hyperkalemia have been described, which were induced by upregulation of muscular nicotinic receptors.[9,10] This upregulation is quantitative and also qualitative with immature ($\alpha1\alpha1\delta\beta\gamma$ and $\alpha7$) and

mature ($\alpha 1\alpha 1\delta\beta\varepsilon$) receptors in the neuromuscular junctional and extrajunctional areas.[8,9]

Risk Factors of Potassium Increase

First, immobilization in the ICU, possibly associated with neuromuscular dysfunction, could provoke receptor upregulation and hyperkalemia after succinylcholine injection.[25,26] Fink et al.[26] showed a decrease of muscle strength, a loss of muscular mass, and an increase of cholinergic receptors after 12 days of immobilization in rats with a greater effect when inflammation was associated. Another study showed an increase of the number of cholinergic receptors, correlated with ΔK, after 28 days of immobilization in rats.[21] In fact, the immobilization length of time is difficult to measure but the length of ICU stay could be considered an indirect marker. A univariate analysis of 23 ICU patients found that potassium at 5 minutes after succinylcholine injection was correlated with the length of ICU stay ($r = 0.39$; $P < 0.05$).[17] In the present study of 153 ICU intubations, the only factor independently associated with ΔK was the length of ICU stay before intubation ($\rho = 0.561$, $P < 0.001$). For intubations before 16 days of ICU stay, the median ΔK was 0.25 mmol/L (0–0.6 mmol/L), comparable to the standard population,[11] whereas the median ΔK was 1.9 mmol/L (0.7–2.8 mmol/L) after 16 days.

Second, the prolonged administration of nondepolarizing neuromuscular blocking drugs has been found to be associated with an increase in cholinergic receptors, leading to acute hyperkalemia, in some experimental studies.[8,9,21] In our study, despite the small sample size of patients, the use of a nondepolarizing neuromuscular blocking drug was not independently associated with ΔK after succinylcholine injection.

Third, the origin of a neurologic deficit could have different consequences on cholinergic receptor upregulation and ΔK. After univariate analysis, we found that the median ΔK of the patients with cerebral motor deficits was significantly higher than median ΔK of patients with motor deficit from spinal cord or peripheral injuries and patients with no motor deficits ($P = 0.042$). The small sample size of patients and the different delays in motor deficit made the interpretation of this analysis uncertain. To our knowledge, no study analyzed cerebral deficit as a risk factor of hyperkalemia after succinylcholine injection. No clinical problem was observed during this study and case reports or experimental studies described only increase of potassium after neurologic deficit induced by nerve section or spinal cord injury.[8–10,13,18–20] Further research to analyze cerebral deficit as a risk factor of hyperkalemia after succinylcholine injection is warranted.

Finally, it is unclear whether infection and/or inflammation can induce an increase in the number of receptors to a critical level at which potassium is massively released, particularly in the absence of immobilization. Few cases of hyperkalemia have been reported in septic patients after succinylcholine injection, but all patients were immobilized.[9,27] An inflammatory or infectious state induced in animals not immobilized did not increase cholinergic receptor number in some experimental studies,[28,29] whereas systemic inflammation over 12 days in immobilized rats has shown an increase of cholinergic receptors with greater effect.[26] In our study, presence of sepsis was not independently associated with ΔK after succinylcholine injection.

Risk Factors of Hyperkalemia ≥6.5

Length of ICU stay, an indirect etiologic factor of immobilization, was associated with $K_{after} \geq 6.5$ ($P < 0.001$) after multivariate analysis in our study. An arbitrary threshold of 10 days of ICU stay had been chosen by Castillo et al.[17] with a mean ΔK of 0.5 mmol/L before and 1.8 mmol/L after. We used a ROC curve analysis and found that a threshold of 16 days' stay in our ICU was very predictive of $K_{after} \geq 6.5$ mmol/L after succinylcholine injection with 90.9% (95% CI: 58.7%–98.5%) sensitivity and 90.1% (95% CI: 84%–94.5%) specificity. Acute hyperkalemia ≥6.5 was observed in only 1% (95% CI: 0%–4%) of cases during the first 16 days compared with 37% (95% CI: 19%–58%) after the 16th day.

In the literature, acute cerebral pathology was not found to be an independent risk factor of hyperkalemia after succinylcholine injection.[9] After multivariate analysis, its presence was associated with $K_{after} \geq 6.5$ ($P = 0.047$) but not with ΔK ($P = 0.102$), independently of the presence of motor deficit >48 hours or length of stay in the ICU in all analyses. One explanation could be the depth of sedation, which could be different in the case of acute cerebral pathology. In case of intracranial hypertension, patients are deeply sedated with probable increased risks of neuromuscular dysfunction. However, continuous sedation data were not collected in our study.

Limits

There are some limitations to this study. First, it was an observational study in which one-third of the patients were excluded because the primary outcome (arterial potassium) was not measured. Because of the large number of patients who did not meet the inclusion criterion, we ensured that the main results remained valid in the extreme case of lack of hyperkaliemia in the excluded patients. Nevertheless, the length of ICU stay was significantly predictive of hyperkalemia ≥6.5. Moreover, only 11 intubations with hyperkalemia ≥6.5 mmol/L after succinylcholine injection were observed, which was a small sample for the statistical analysis of associated etiologic factors, but the analysis of ΔK of the 153 intubations had more statistical power.

Second, the study was monocentric and the 16-day threshold could be different in other ICUs with different pathologies, muscular mobilization, or sedation protocols.

Finally, we analyzed ΔK, acute hyperkalemia, and clinical arrhythmias but we did not precisely study electrocardiographic derivations (such as T wave). In 153 intubations, only 2 cardiac arrhythmias were observed in patients with $K_{after} \geq 6.5$ after succinylcholine injection and these 2 arrhythmias were reversible after calcium treatment. The choice of treatment for these acute hyperkalemia and clinical arrhythmias was left to the referring physician.

CONCLUSION

This prospective, observational study of use of succinylcholine for ICU intubation shows that the length of ICU stay before intubation is the only factor correlated with ΔK after

multivariate analysis. Of the 153 intubations using succinylcholine, 11 cases of hyperkalemia ≥6.5 were observed and the factors associated with hyperkalemia ≥6.5 after multivariate analysis were the length of ICU stay ($P < 0.001$) and the presence of acute cerebral pathology ($P = 0.047$). The risk of hyperkalemia ≥6.5 mmol/L was found highly significant after the 16th day (37% [95% CI: 19%–58%]) compared with only 1% (95% CI: 0%–4%) when succinylcholine was injected during the first 16 days.

DISCLOSURES

Name: Antonia Blanié, MD.
Contribution: This author helped design the study, conduct the study, analyze the data, and write the manuscript.
Attestation: Antonia Blanié has seen the original study data, reviewed the analysis of the data, approved the final manuscript, and is the author responsible for archiving the study files.
Name: Catherine Ract, MD.
Contribution: This author helped conduct the study and write the manuscript.
Attestation: Catherine Ract has seen the original study data and approved the final manuscript.
Name: Pierre-Etienne Leblanc, MD.
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Contribution: This author helped conduct the study and write the manuscript.
Attestation: Jacques Duranteau approved the final manuscript and is the author responsible for archiving the study files.
Name: Bernard Vigué, MD, PhD.
Contribution: This author helped design the study, conduct the study, analyze the data, and write the manuscript.
Attestation: Bernard Vigué has seen the original study data, reviewed the analysis of the data, approved the final manuscript, and is the author responsible for archiving the study files.
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The Frequency and Magnitude of Cerebrospinal Fluid Pulsations Influence Intrathecal Drug Distribution: Key Factors for Interpatient Variability: Erratum

In the article that appeared on page 386 in the August 2012 issue of volume 115 of *Anesthesia & Analgesia*, the authors discovered an inconsistency and wish to make the following statement: "All reported CINE-MRI measured and computed cerebrospinal fluid velocities in this article are rostral-caudal velocities."

Reference:

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