Retrospective evaluation of cats with elapid snake envenomation associated neurotoxicity requiring mechanical ventilation: 12 cases (2005-2014).

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Running title: Feline snake envenomation ventilation

Abbreviations

CI Confidence interval

CK Creatine kinase

MV Mechanical ventilation

STD Survival to hospital discharge

SVDK Snake venom detection kit

UMUVH University of Melbourne UVet Werribee Animal Hospital

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Abstract

Objective – To retrospectively determine the population and outcome characteristics of a cohort of Australian elapid snake envenomed cats requiring mechanical ventilation (MV).

Design – Retrospective observational study (2005–2014).

Setting – Academic veterinary emergency and critical care service.

Animals – 12 cats undergoing MV for elapid snake envenomation.

Interventions – None

Measurements and Main Results – The medical records were searched to identify cats requiring MV as part of treatment for elapid snake envenomation. Signalment, the indication for, duration of and complications associated with MV, duration of hospitalization and survival to hospital discharge were recorded for each of the enrolled cases. Seven cats (58.3%) underwent MV because of presumed unsustainable respiratory effort and 5 cats (41.7%) for respiratory arrest. Eleven cats (91.7%) were successfully weaned from MV and survived to hospital discharge. No cats developed ventilator associated pneumonia or pneumothorax. The median duration of MV was 19.5 hours for the survivors (range 7.0–37.0 hours) and median duration of hospitalization was 3.5 days (range 2.4–14.9 days).

Conclusions – Cats requiring MV for elapid snake envenomation have a favorable outcome and require a relatively short period of MV. Complications encountered are unlikely to influence outcome.

Keywords

Elapidae, hypoventilation, intermittent positive-pressure ventilation, neuromuscular diseases, snake bites

Introduction

Elapid snake envenomation in dogs and cats is a common occurrence in Australia during the warmer months of the year.¹ The elapid snakes most frequently encountered in the outer western suburbs of Melbourne are the mainland tiger snake (*Notechis scutatus*) and the eastern brown snake (*Pseudonaja textilis*).^{2,3} Both species rank amongst Australia's most venomous snakes.⁴

Mainland tiger snake venom contains notexin, a phospholipase A₂, which causes a dose-dependent, local and systemic myodegeneration and redistribution of intracellular acetylcholine such that its availability for neuromuscular transmission is reduced.⁵⁻⁸ The venom also comprises other less potent, pre-synaptic phospholipase A₂ enzymes that directly inhibit acetylcholine release and further contribute to neuromuscular paralysis.⁹ Additionally, the venom contains several reversible post-synaptic neurotoxins and a potent factor Xa-like prothrombin activator, notecarin D.^{5, 10-14} The combined effect of these toxins results in rhabdomyolysis, lower motor neuron paralysis and venom induced consumptive coagulopathy. With the exception of myopathy, similar abnormalities occur in eastern brown snake envenomed dogs and cats. However, the clinical phenotype is caused by a distinctly different set of venom components, namely textilotoxin, a potent pre-synaptic phospholipase A₂ neurotoxin, pseudonajatoxin, a post-synaptic peptidic neurotoxin, and pseutarin C, a factor Xa-Va-like prothrombin activator.^{5, 10-12} A characteristic clinical syndrome results from envenomation by either of these snakes. Envenomed cats typically present with mydriasis, decreased to absent pupillary light reflexes, hindlimb ataxia, generalized muscle weakness, flaccid paralysis, vomiting and tachypnea or dyspnea.^{3, 15, 16}

Elapid snake envenomation has the potential to cause significant morbidity and mortality. The reported survival rate for cats not treated with antivenom ranges from 66% to 70%.^{1, 15} While snake envenomation can be treated successfully with antivenom and

supportive care (comprising intravenous fluids, analgesia and nutrition), severely affected animals may succumb to respiratory failure subsequent to extensive neuromuscular weakness unless mechanical ventilation (MV) is instituted. There is a paucity of information relating to elapid snake envenomed cats requiring MV. Reported cases consist of small subgroups within larger studies examining snake envenomation or MV.^{3, 17} The main objective of the present study was to retrospectively describe the characteristics, management and clinical outcome of a population of elapid snake envenomed cats requiring MV. We hypothesized that elapid snake envenomed cats requiring MV would have a short duration of MV and a good prognosis for discharge from hospital.

Material and Methods

The electronic medical records of the University of Melbourne UVet Werribee Animal Hospital (UMUVH), a university veterinary teaching hospital, were queried for the species 'cat' and for the keywords 'snake' and 'ventilation' in the history text. The search was limited to animals admitted between 1 January 2005 and 31 December 2014. Cases were included in the analysis if the diagnosis of elapid snake envenomation was made and MV was part of the treatment.

Snake bites are rarely witnessed in cats and, therefore, the clinical diagnosis is predominantly based on pattern recognition. For the purpose of this study, elapid snake envenomation in cats was defined as the presence of an appropriate history, characteristic clinical signs and at least 1 of the following:

1. A positive urine or blood snake venom detection kit (SVDK)^a result on initial presentation or following initial antivenom therapy
2. A blood creatine kinase (CK) concentration ^{b,c} > 1000 U/L¹⁸

3. Laboratory evidence of a snake venom induced consumptive coagulopathy as

demonstrated by a markedly prolonged or activated clotting time.^d

Cats that were diagnosed with snake envenomation requiring MV that were euthanized prior to initiation of MV were excluded from the study. Comorbidities were not an exclusion criterion.

The following data were obtained from the medical record of enrolled cases: signalment and body weight, information relating to the snake bite, clinical signs at presentation, the maximum CK value measured during hospitalization, the use and result of the SVDK, the dose of antivenom administered, the indication, duration and complications associated with MV, duration of hospitalization and survival to hospital discharge (STD). Where available, the following emergency database values at presentation were recorded: PCV, refractometric total solids, venous acid-base and blood gas variables^e, glucose^e, lactate^e, electrolytes (sodium, potassium, chloride, ionized calcium)^e and coagulation test results (activated clotting time^d). Two types of intensive care ventilators were in use during the study period to undertake MV of the cats.^{f,g} The initial settings used were those specified in the UMUVH practice protocol: volume control, 100% FiO₂, respiratory rate of 20/min, tidal volume of 10 mL/kg, positive end-expiratory pressure of 3-5 cm H₂O. Following this, accepted practice was to adjust the ventilator settings according to patient response so as to maintain SpO₂ ≥ 95% and PvCO₂ < 55 mm Hg. This was to reduce the risk of hypoxemia or oxygen toxicity and to allow for permissive hypercapnia if needed as a strategic element of lung-protective ventilation. Spontaneous breathing trials were conducted at least once every 12 hours, but at the discretion of the primary clinician in charge. During such a trial, MV was discontinued if the spontaneously ventilating cat was able to consistently maintain a SpO₂ of more than 92% with or without oxygen supplementation, and a PvCO₂ < 50 mm Hg with normal or mildly increased respiratory effort as assessed by the primary clinician. Standard

physiologic monitoring consisted of continuous electrocardiogram, indirect blood pressure, pulse oximetry and capnography, and a protocolized ventilator specific nursing care regimen was applied as previously described.¹⁹

If an induction agent was required for orotracheal intubation, alfaxalone^h, propofolⁱ, or a benzodiazepine was administered intravenously with or without an opioid. To allow maintenance of the endotracheal tube and MV, a benzodiazepine, opioid or anesthetic agent such as alfaxalone or propofol was administered as a constant rate infusion, either in isolation or in various combinations, and titrated to the needs of the patient.

Statistical Analysis

Study data were collected and managed using REDCap, a secure, web-based application for research data capture hosted at the Faculty of Veterinary and Agricultural Sciences of the University of Melbourne.²⁰ Statistical analyses were performed using commercially available software.^j

For categorical (nominal and ordinal) variables the proportions of response frequencies were presented as percentages. Confidence intervals for proportions were reported for variables where such information was meaningful (eg, gender, clinical signs, STD, adverse events). The Shapiro-Wilks test was used to assess continuous data for normality. If affirmative, data were expressed as means and standard deviations while medians and ranges were used to describe nonparametric data. The Pearson Chi-square test was used to identify differences in variable frequencies (eg, male versus female). The α -value was set at $P < 0.05$.

Results

Case selection

A total of 70 medical records of feline snake envenomation events were initially identified upon interrogation of the electronic medical record database. When censoring for cases not

fulfilling the predefined criteria of snake envenomation for this study, 52 case records remained for further analysis. Thirty-three cats were treated without MV. In the remaining 19 cats, MV was recommended, but seven of these animals were euthanized. In 4 of these cases, euthanasia primarily occurred for financial reasons, while the reason for euthanasia was not recorded for the other 3 animals. The remaining 12 cats received MV and met the criteria for inclusion in the study.

Signalment and body weight

Ten cats (83.3%) were neutered males and 2 (16.7%) were neutered females ($P = 0.02$).

Represented breeds were: domestic shorthair (5/12, 41.7%), domestic medium hair (1/12, 8.3%), domestic longhair (1/12, 8.3%), Bengal (1/12, 8.3%) and Burmese (4/12, 33.3%). The cats were 3.5 ± 2.6 years (range 0.6–9 years) old and weighed 4.73 ± 0.89 kg.

Information relating to the snakebite and clinical signs

There was no record of witnessed snake bite in any of the cases. Clinical signs reported by the cat owners or observed by the attending clinician at presentation included in order of frequency: weakness and collapse (11/12, 91.7%), mydriasis (11/12, 91.7%), severely reduced respiratory effort or respiratory arrest (9/12, 75.0%), sluggish or absent pupillary light reflexes (7/12, 58.3%), cyanosis (5/12, 41.7%), vomiting (2/12, 16.7%), generalized muscle twitching or tremors (2/12, 16.7%), absent gag reflex (1/12, 8.3%) and dysphagia (1/12, 8.3%).

Clinical pathology

Nine (75.0%) cats had SVDK performed, 4 (44.4%) prior to receiving treatment and 5 (55.6%) following initial antivenom therapy. Six (66.7%) were positive for the tiger snake immunotype, 1 (11.1%) was positive for the brown snake immunotype and 2 (22.2%) were negative. The cats that tested negative had prior antivenom treatment. Three (33.3%) tests

were performed using urine and 2 (22.2%) using whole blood. The sample matrix used was not stated for 4 cases.

The emergency database values and coagulation test results obtained within the first 60 minutes of admission to the hospital are listed in table 1. Mild to moderate hyperglycemia and hyperlactatemia were observed in 54% and 70% of the animals respectively. All venous PCO₂ values were elevated with 60% of the values exceeding 60 mm Hg. The median peak CK recorded was 25,585 U/L (range 2,256–98,310 U/L) and was determined on day 2 (median, range 1–12 days) of hospitalization.

Pharmacological intervention

All cats were treated with bivalent tiger-brown antivenom. Two different antivenoms were used in the time period of this study. One^k contained a minimum of 3000 units and 1000 units of mainland tiger snake and eastern brown snake antivenom respectively while the other^l contained a minimum of 3000 units and 4000 units of mainland tiger snake and eastern brown snake antivenom respectively. Most (11/12, 91.7%) cats received antivenom at UMUVH and one (8.3%) at a referring veterinary clinic. Five (41.7%) cats received one vial^k, five (41.7%) cats received two vials^{k,l} and two (16.7%) cats received three vials^l. No adverse reactions to antivenom administration were reported.

Clinical course and outcome

The majority of cats (9/12, 75%, $P = 0.08$) were placed on MV at the time of presentation, while 3 cats received supplemental oxygen for a short time (1, 2 and 3.5 hours; mean 2.17 ± 1.26 hours) prior to MV. Five cats (41.7%, CI 19.3–68.0%) were mechanically ventilated due to respiratory arrest. The remaining seven animals (58.3%, CI 32.0–80.7%) were assessed to have reduced ventilatory effort that was considered unsustainable. Eleven cats (91.7%, CI 64.6–98.5%) were successfully weaned from MV and survived to hospital

discharge. The cat that did not survive was euthanized after 31 hours of MV after weaning from MV failed. In survivors, the mean duration of MV was 22.7 ± 9.2 hours (range 7.0–37.0 hours) and the median duration of hospitalization was 3.5 days (range 2.4–14.9 days). No adverse hemodynamic effects associated with the use of positive end-expiratory pressure were encountered. After extubation, nine (81.8%, CI 51.6–94.5) of the surviving cats were placed in an oxygen cage for a duration of 10.3 ± 8.42 hours (range 1.0–29.0 hours) with a targeted FiO_2 ranging from 0.3 to 0.5. Pneumonia was diagnosed in 1 cat (8.3%, CI 1.5–35.4%) during MV based on radiographic evidence of alveolar pulmonary disease and the presence of septic suppurative inflammation from an endotracheal wash. Two other cats were suspected to have pneumonia at the time of weaning from the ventilator. *Bordetella bronchiseptica* was cultured from an endotracheal sample collected from one of these cats. The second cat had tachypnea, increased respiratory effort, pyrexia and a degenerative left shift with toxic change. Neither of these cats had thoracic radiographs taken. From the record, other complications noted during MV included: hypothermia (range 32.2°C to 36.3°C) (11/12, 91.7%, CI 64.6–98.5%), hyperthermia/ pyrexia (range 39.5°C to 40.6°C) (4/12, 33.3%, CI 13.8–60.9%), anemia (PCV range 25.5% to 28%) (4/12, 33.3%, CI 13.8–60.9%), ventricular arrhythmia (2/12, 16.7%, CI 4.7–44.8%), alveolar pulmonary disease with enlarged caudal lobar vessels suggestive of fluid overload/ cardiogenic pulmonary edema (2/12, 16.7%, CI 4.7–44.8%), a newly diagnosed renal azotemia (1/12, 8.3%, CI 1.5–35.4%), and presumptive upper gastrointestinal tract bleeding (1/12, 8.3%, CI 1.5–35.4%). Seven (58.3%, CI 32.0–80.7%) cats were noted to have corneal ulcers following MV.

Discussion

In this study, the STD rate for elapid snake envenomed cats undergoing MV was 91.7%. This positions the outcome for these cats at the high end of the previously reported 15% to 83.3%

survival rates in feline patients ventilated for all causes.^{17, 21-25} This favorable outcome statistic is likely due to the reversible nature of the underlying neuromuscular disease and the fact that the surviving cats in the present study did not initially have or acquire any severe pulmonary parenchymal disease during MV. Reported STD rates for ventilated cats and dogs range from 39% to 69% for neurological causes, but only from 20% to 42% for pulmonary causes.^{17, 21, 23} Within the subgroup of neuromuscular disease, cervical spinal cord disease and lower motor neuron diseases (eg, myasthenia gravis and polyradiculoneuritis) have reported STD rates ranging from 50% to 71% in dogs and 21% to 57% in cats.^{23, 26, 27} Those requiring MV for tick paralysis and elapid snake envenomation, after censoring for cost-based euthanasia had more favorable outcomes, with 71% to 75% of dogs and 82% of cats surviving to hospital discharge.^{17, 25} Two main reasons may contribute to these STD rates. First, most tick and elapid snake envenomed patients require MV for hypoventilation and unsustainable respiratory effort rather than for hypoxemia due to pulmonary pathology.^{17, 25} Second, the reported ventilation times after tick paralysis and elapid snake envenomation were markedly shorter than for other causes of lower motor neuron paralysis. This is ascribed to the prompt neutralization of the neurotoxin with antivenom leading to rapid improvement of paralysis.^{17, 25, 28} This is in line with the ventilation times found in our study. Similar durations of ventilation have also been reported in the management of respiratory failure in humans with neurotoxic snake envenomation.^{29, 30} Independent of the cause, a prolonged duration of MV translates into an increased likelihood of developing complications such as ventilator associated pneumonia, which can lead to worsened pulmonary function, prolonged hospitalization, reduced weaning success rates and STD, and additional expense.^{31, 32}

Compared to dogs, cats are reported to have worse ventilator weaning rates when undergoing MV for any reason, with ventilator weaning rates for cats ranging from 15% to 25% and for dogs, from 44% to 45%.^{22, 23, 33} This has been attributed to the smaller size of

cats which could make MV and monitoring technically more challenging.^{22, 23} However, outcomes are also influenced by the primary disease process and the basis for MV as previously mentioned. Reported survival for cats undergoing MV for tick paralysis and elapid snake envenomation is good. In a retrospective study of 54 dogs and 7 cats undergoing MV for tick paralysis, 83.3% of cats and 73.9% of dogs survived after excluding cost-based euthanasia cases.²⁵ Seventy-one percent of the cats in that study underwent MV because of hypoventilation compared to 33% of the dogs. Another retrospective study including 42 dogs and cats treated with MV for elapid snake envenomation reported a STD rate of 82% in this subgroup. However, the weaning success and STD rates for the elapid snake envenomed cats were not reported separately in this study.¹⁷ Nevertheless, the same study suggests that cats and dogs undergoing MV for elapid snake envenomation might be expected to have a favorable outcome, and our study results further corroborate this finding specifically for cats.

In our study, 1 cat was diagnosed with pneumonia and 2 others were suspected of having the disease. The exact number of cats with pneumonia could not be ascertained because not all the cats had thoracic radiographs, neither were endotracheal samples collected for cytological examination and culture in all instances. Because all 3 cats were mechanically ventilated for less than 24 hours, the term ventilator-associated pneumonia cannot strictly be applied to these cases.³¹ It is possible that aspiration subsequent to vomiting or pre-existing disease were the cause of the confirmed and suspected pneumonia in these cats. The minor role that pneumonia played in the cats herein, is in line with the findings in a previous study where no instances of aspiration pneumonia were reported in dogs or cats undergoing MV for elapid snake envenomation.¹⁷ Pneumothorax, reported to occur in 3% to 29% of dogs or cats ventilated for different reasons, was not reported in any of the cats in this study possibly indicating that aggressive ventilator settings with high peak pressure were not required in these animals.^{17, 21-23, 33}

Hyperglycemia and hyperlactatemia were present in some cats in our study, which may reflect metabolic distress. An interesting finding was that a significantly larger proportion of the cats were neutered males as compared to neutered females, possibly explained by gender-specific behavioral variations leading to a higher exposure to snakebite. The absence of old cats in the study population may be interpreted similarly. However, the demographic of cats with elapid snake envenomation has not previously been examined and should be explored in larger studies. A secondary finding of this study was that antivenom is highly effective in reversing otherwise lethal elapid snake envenomation, if aggressive temporary supportive care is provided. As all but one animal survived, statistical analysis regarding possible association between outcome and demographic variables, clinicopathological changes and specific pharmacologic interventions was not attempted and remains to be further explored in a larger study.

The present study has several limitations that require consideration when interpreting its results. First, the small number of cats in the study affects the precision of the STD rate observed. Evaluation of a larger population would be required to further corroborate our key finding of a favorable outcome in elapid snake envenomed cats requiring MV, and may also allow for the identification of statistical associations between different clinicopathological factors and outcome. Second, the study is retrospective in nature and the data spans a decade. This precludes control over original data collection and data quality, introduces identifiable and non-identifiable variation in case management over time, and prevents avoidance of missing data. The study protocol explicitly allowed inclusion of cases into the study despite missing secondary outcome data (eg, extended data base variables, coagulation variables). Nevertheless, these factors restrict the data that can be examined and impact upon the interpretation of available results. More importantly, primary outcome data (ie, duration of ventilation, STD) was available for all cases, such that the study's key findings remain valid.

Third, a positive snake venom detection test result was not achieved in 42% of the cats.

However, this does not preclude a correct diagnosis of elapid snake envenomation in these cats because they had, in addition to the appropriate history and clinical signs, other laboratory test results, such as a marked prolongation of coagulation times and an elevated CK, to support the diagnosis. Moreover, a proportion of these cats received antivenom prior to SVDK use; sufficient administration of the appropriate antivenom results in the binding and neutralization of circulating venom and accordingly, a negative SVDK result. Fourth, even though the species of snake was not positively identified in all cases, based on the clinicopathologic findings on presentation and known snake species in the region, it is most likely that the mainland tiger snake and the eastern brown snake were the species of snake involved. Fifth, the decision to initiate MV was based on the primary clinician's perceived need and not on set, quantified metrics. However, the severe hypercarbia observed in the overall population and the respiratory arrest observed in five cats would suggest that the indication for MV was valid.

Conclusions

The main findings of this small retrospective study suggest that in cats with severe elapid snake envenomation leading to actual or presumed impending respiratory failure, treatment with antivenom, intensive care and MV will lead to a good prognosis. The duration of MV is expected to be less than 36 hours and MV is unlikely to be associated with serious adverse effects. Further research based on a larger study population is needed to corroborate these findings in different settings and to determine if patient, snake bite or treatment variables influence relevant outcomes such as STD, duration of ventilation and hospitalization.

Footnotes

- a Snake Venom Detection Kit, Commonwealth Serum Laboratories, Parkville, VIC, Australia
- b Cobas Integra 400 plus, Roche Diagnostics Australia Pty Limited, Castle Hill, NSW, Australia
- c VetScan VS2, Abaxis Inc., Union City, CA
- d Celite ACT tubes, Helena Laboratories, Mount Waverley, VIC, Australia
- e Radiometer ABL800 BASIC Analyzer, Radiometer Pacific Pty. Ltd., Mount Waverley, VIC, Australia
- f Bear Cub 750 PSV, Bear Medical Systems Inc., Palm Springs, CA
- g Siemens Servo 300, Siemens-Elema AB, Electromedical Systems Division, Solna, Sweden
- h Alfaxan, Jurox, Rutherford, NSW, Australia
- i Provive 1%, Claris Lifesciences, Burwood, NSW, Australia
- j JMP 12.0, SAS Institute Inc., Cary, NC
- k Tiger-Brown Snake Combined Antivenom, Commonwealth Serum Laboratories, Parkville, VIC, Australia
- l Tiger Multi-Brown Snake Antivenom, Summerland Serums, Alstonville, NSW, Australia

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Table 1: Clinicopathologic values measured within 1 hour of admission.^e

Variable	N (% of total)	Mean	SD	Median	Percentile (0.05, 0.95)	Reference range
Venous pH	10 (83.3)	7.12	0.13	7.15	(6.84, 7.27)	7.33–7.48
PvCO ₂ (mm Hg)	10 (83.3)	69.26	28.66	63.45	(40.70, 141.00)	34-39
Venous SBE (mmol/L)	10 (83.3)	-7.29	3.71	-7.65	(-10.70, 0.80)	-5 to 0
PCV (%)	10 (83.3)	46.7	5.42	47.0	(37, 54)	30-45
Total solids (g/L)	10 (83.3)	73.80	9.16	73.00	(62, 90)	60-80
(g/dL)		7.4	0.9	7.3	(6.2, 9.0)	6.0-8.0
Sodium (mmol/L)	10 (83.3)	150.9	4.31	150.5	(142, 156)	149–155
Potassium (mmol/L)	10 (83.3)	3.44	0.21	3.45	(3.0, 3.7)	3.6–4.1
Chloride (mmol/L)	10 (83.3)	119.6	4.86	120.5	(113, 126)	118–124
Ionized calcium (mmol/L)	10 (83.3)	1.34	0.08	1.32	(1.24, 1.48)	1.1–1.3
Glucose (mmol/L)	11 (91.7)	10.01	4.75	8.50	(4.3, 19.4)	4.1-8.2
(mg/dL)		180.2	85.5	153.0	(77.4, 349.2)	73.8-147.6
Lactate (mmol/L)	10 (83.3)	3.19	1.84	3.15	(0.7, 5.6)	< 2.0
ACT (seconds)	5 (41.7)	151.6	54.19	148.0	(80, 232)	55-165

ACT, activated clotting time; SBE, standard base excess

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