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Lizard anesthesia—a retrospective study of anesthetic protocol and monitoring quality of anesthetic episodes at a veterinary hospital over 23 years (2000–2023)

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Objective
This study's aim was to summarize the anesthetic events of lizards seen at a university hospital, identify challenges with record-keeping, and assess anesthesia-related mortality.

Methods
From October 2000 through January 2023, medical records of lizards that underwent general anesthesia were reviewed. Cases with complete anesthesia records were used to assess anesthetic parameters. Collected data included general patient details, diagnosis, procedures, premedication, induction, maintenance, monitoring, and recovery. The recorded duration of each of these periods, when documented, was reported for each patient, alongside what drug protocols were utilized and compiled to give an overarching view of trends in anesthesia at the hospital. The times were also analyzed to assess whether any drug/protocol led to more negative outcomes or prolonged anesthetic duration.

Results
A total of 104 anesthetic events were performed. Ninety-nine cases had detailed reports available for analysis. A records review identified issues that frequently resulted in poor record management and highlighted the most used anesthetic agents. For premedications, alfaxalone, butorphanol, midazolam, and hydromorphone were common. During induction, alfaxalone or propofol was the most common. For maintenance, isoflurane and sevoflurane were comparable, while alfaxalone was favored for noninhalants. Of the 99 cases analyzed, 95 recovered, 3 were euthanatized due to poor prognosis, and 1 failed to recover; the 1 that failed to recover had significant underlying disease identified.

Conclusions
The trend of maintenance alfaxalone constant rate infusions replacing inhalants is the major development. The records for anesthesia have improved over time, with the exception of anesthesia time records. It is recommended to implement an automated system that records vitals intermittently alongside implementation of an updated anesthesia sheet with areas dedicated to common research values.

Clinical Relevance
General anesthesia can be reliably and safely undertaken in lizards without severe pre-existing disease. Efforts should focus on identifying preexisting disease, creating uniform systems for assessing anesthetic stages, and limiting record-keeping variance.

Keywords: anesthetic, recovery, alfaxalone, lizards, premedication

Lizard anesthesia is a significantly understudied branch of veterinary medicine. When compared to typical companion animals, lizards have significant differences in both their anatomy and physiology, which make it challenging to develop good anesthetic protocols in these species. These differences include the absence of a functional diaphragm; a 3-chambered heart (ie, 2 atria and 1 ventricle)[1], which facilitates intracardiac shunting (ie, mixing of oxygenated and deoxygenated blood); a wide variety of lung structures dependent on the specific species, ranging from simple to multichambered lungs that allow for unidirectional pulmonary airflow (like birds)[2–5]; and hepatic and renal portal systems,[6,7] which contribute to more rapid drug metabolism and clearance.[1–7] The exception to both the absence of a functional diaphragm

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and a 3-chambered heart structure is varanids, which have a diaphragm and a functionally divided cardiac ventricle.[8] Reptiles also typically have reduced heart, respiratory, and metabolic rates compared to endotherms. They are ectothermic, which means they are dependent upon environmental temperatures and behaviors to regulate their body temperature. Because their cellular metabolism is tied to their thermoregulation, any decrease or increase in environmental temperature can lead to similar changes in cellular metabolism, oxygen demand, and again systemic distribution and clearance of drugs.[9] As a result, any discrepancies in ambient temperature along with hepatic and renal first-pass effects associated with caudal body drug administration all number among the unique challenges for reptile anesthesia.[6,10–12] Body size is another factor to consider. Many patients are too small to intubate, or venous access is impossible to obtain in certain species. Constraints associated with required blood volume for testing, particularly in small patients, further complicate screening prior to sedation for diseases such as kidney and liver dysfunction that could negatively impact anesthetic outcomes. It should be understood that many of the monitoring devices utilized in traditional small animal anesthesia serve a reduced function with lizards. Some examples of this include the utilization of end-tidal CO_2 ($ETCO_2$) and blood oxygen saturation (Spo_2) primarily to monitor trends rather than analyzing actual values, as the previously mentioned shunting can skew these values. Another example is that for cardiac assessment, blood pressure is near impossible to gauge due to the small size of many lizard patients alongside difficulty gaining arterial access as well as the fact that Doppler detection of a heartbeat does not necessarily mean the animal is alive.[13]

Significant advancements have been made in the field of reptile medicine as a whole and anesthesia over the past 2 decades. Many of these advancements include the development of new anesthetic compounds and better protocols for administering injectable and inhalant anesthetics.[14–17] Retrospective reviews of anesthetic use and safety in reptiles are largely lacking and represent a knowledge gap in need of filling. This has led to utilization of anecdotal evidence, literature that studies individual drugs in a small sample size, and personal experience to dictate the choices of many practitioners.[18,19]

The primary purpose of the present report was to address the current need for a large-scale overlook into lizard anesthesia by analyzing the anesthetic trends and results in a veterinary referral hospital. We hypothesized that the anesthetic standards and protocols in the field have changed over the years, shifting from the predominant use of inhalants to more frequent incorporation of injectable compounds in anesthetic protocols. This review aimed to reveal specific areas in need of improvement, particularly problem areas within record-keeping and vital monitoring. The review also aims provide evidence that lizard anesthesia can be achieved and maintained at a similar standard of care as that of small animal anesthesia, when taking into account the unique difficulties and differences that the anatomy and physiology pose to monitoring methods. This standard of care includes a thorough preoperative workup, including bloodwork when possible, as well as monitoring similar vitals, even if only to watch trends.

Methods

Case selection criteria

Medical records of lizards that underwent general anesthesia at the University of Georgia's Veterinary Teaching Hospital from October 2000 through January 2023 were reviewed. Cases were identified and included by searching the hospital's electronic medical record system for lizards that received anesthetic-related charges on their invoice. The patient's complete medical records, once identified, were screened and data from each anesthetic event documented. All cases were included in the present study to evaluate patient demographics. The criterion of inclusion for further analysis was that an anesthesia record for the episode be available for analysis. Exclusion criteria consisted of anesthetic events without detailed anesthesia records that could not be used to assess anesthetic times, patient vitals, and outcomes. All records underwent a thorough evaluation for their overall quality using parameters similar to those outlined in Morrison et al.[20]

Statistical analysis

Data reported on anesthesia records were used to perform statistical analyses (ie, calculating means and SDs or medians and ranges using JMP statistical software [JMP Statistical Discovery LLC]) for age, sex, body weight, body condition score (BCS), retrospective American Society of Anesthesiologists (ASA) status, injectable anesthetic dose or concentration of inhalant, and anesthesia time points (ie, time between premedication and induction agent administrations, time between induction and maintenance agent administrations, duration of inhalant or injectable anesthesia, duration of procedure, duration of recovery, and total anesthesia time), and nadir and peak values of vitals were also reported (ie, heart rate, respiratory [ventilation] rate, $ETCO_2$, and Spo_2). Mean and SD values were reported as mean ± SD.

Results

Patient demographics

A total of 104 anesthesia cases were reported over a 23-year period at the University of Georgia Veterinary Teaching Hospital **(Table 1)**, which included data from 94 lizards belonging to 8 families of Squamata—Agamidae, Chamaeleonidae, Eublepharidae, Gekkonidae, Helodermatidae, Iguanidae, Teiidae, and Varanidae; in 5 animals, the genus and species were unknown **(Supplementary Tables S1 and S2)**. This dataset consisted of animals (60% male, 30% female, and 10% sex unknown) that were classified as either personal pets or educational animals. Mean and SD values reported below were calculated from data obtained from all lizards anesthetized; additional subcategorized values are available

Table 1—Lizard anesthesia dataset summary, highlighting the number and percentage of available records for analyses.

Dataset assessment of anesthesia records used in present study	Total (N)	Total (%)
Anesthesia cases reported between October 2000 and January 2023		
Total No. of anesthesia cases reported	104	100
Anesthesia records available	99	95
Multiple anesthetic events with same individual	10	10
Anesthesia records missing	5	5
Cases available for anesthesia time calculations		
Pre-med duration	74	75
Induction duration	94	95
Procedure duration	75	76
Recovery duration	69	70
Total anesthesia time (premed, duration, and recovery)	69	70
Cases available for anesthesia vital parameters		
$ETCO_2$	67	68
SpO_2	29	29
Heart rate	98	99
Respiratory rate	97	98
Body temperature	77	78
Anesthesia outcome		
Died—elected for humane euthanasia	3	3
Died—failed to recover	1	1
Recovered	95	96

ETO_2 = End-tidal oxygen. HR = Heart rate. RR = Respiratory rate. SpO_2 = Blood oxygen saturation.

in Supplementary Tables S2, **S3, and S4**. Ages of lizards undergoing anesthesia ranged from less than a year up to 19 (5 ± 4) years, while the maximum lifespan was approximately 20 years. The subjective age cutoff of 10 years old for geriatric that was set places the majority of this dataset within the adult range.[10] Body mass (kg) varied among the different lizard species, though, based on overall BCS (3 ± 1), the majority fell within an acceptable weight range. However, the portion of patients undergoing anesthesia with no overt health concerns was in the minority, with the retrospectively assigned ASA status of 1 covering only a small portion of the patients undergoing anesthesia (approx 21%) and the largest category being an ASA status of 3 (approx 35%).

Anesthesia dataset summary and record quality assessment

Ninety-nine cases had complete anesthesia records available for review. Of those reports, 10% were from individuals that had undergone multiple anesthesia events throughout their lifetime (Table 1). Eighty-seven reports included premedication as part of their anesthetic plan, and 74 of 87 of these cases (85%) had accurately recorded premedication duration times that could be used for further analyses. Other anesthetic duration times that were assessed included general anesthesia (maintenance), procedure, recovery, and sum total anesthesia time. Duration of anesthesia was accurately reported in 93 of 99 (94%) of cases, while in the 84 cases where a surgical procedure was conducted, 65 of 84 (77%) accurately reported this time. Only 69 cases perfectly recorded recovery duration, greatly limiting the number of cases where the sum of anesthesia time could be assessed. Anesthesia vital parameters that were most often assessed in patients included $ETCO_2$, SpO_2, heart rate, respiratory rate, and body temperature. The equipment utilized most often to monitor these values was a multiparametric anesthesia monitor.[10] For anesthesia outcomes, of the 99 cases with available records, 95 animals recovered, 3 elected for immediate euthanasia, and 1 failed to recover.

Before any analyses were undertaken, all available reports underwent a quality assessment to identify any underlying issues (detailed in the Methods). Ninety-two anesthetic records were graded as excellent, while the remaining 7 were ranked as good **(Supplementary Table S5)**. Regarding time intervals recorded, 91 cases were classified as excellent or good, and 8 were labeled as lacking or poor; 98 of the 99 cases monitored vitals. Of those, 84 cases were scored as excellent or good, 14 were lacking, and 1 was poor. The area of reporting that was the most lacking was ASA status.

Anesthetic agents and reversals

After record quality assessment, each available record was further analyzed for the drug used in each category—premedication, induction, and maintenance and/or recovery. The duration of time for each anesthetic category (reported in minutes), as well as the average years certain drug combinations or inhalants were used, was also summarized **(Table 2)**. The data revealed that roughly 30% of patients required deep sedation for minor or noninvasive procedures (defined as diagnostic imaging, culture, cytology, or biopsy), while 67% required a surgical plane of general anesthesia. Anesthesia cases were further categorized by the types of anesthetics used. The vast majority of animals

Table 2—Dataset summary of anesthetics used in lizards, showing the number and percentages of anesthetics used for premedications, induction, and maintenance as well as recovery agents. Total cases and percentage cases subdivided by anesthesia level were also reported along with anesthetic routes.

	Anesthetic category and breakdown for groups of ≥ 5 patients										
			Anesthesia level			Total anesthesia times (min)			Year		
	N	% of total	Sedation	Surgical	Euthanasia	N	Mean	SD	Median	Min	Max
Anesthesia records available											
All	104	100.00	7.69	89.42	2.88	69	218.99	88.78	2013	2000	2023
Available	99	95.19	3.03	93.94	3.03	69	218.99	88.78	2014	2000	2023
Anesthetic category											
Injectables	14	13.46	0.00	92.86	7.14	6	256.00	79.03	2020	2002	2022
Combination	74	71.15	1.35	97.30	1.35	58	215.95	90.77	2010	2000	2023
Inhalants	11	10.58	18.18	72.73	9.09	5	209.80	80.56	2015	2000	2022
Missing records	5	4.81	100.00	0.00	0.00	0	.	.	2000	2000	2017
Premed agents											
Alfax, Hydro, Midaz	18	18.18	0.00	100.00	0.00	15	275.87	98.41	2022	2017	2023
Butorphanol	34	34.34	2.94	91.18	5.88	25	190.88	78.32	2004	2000	2011
Butorphanol, Midaz	2	2.02	0.00	100.00	0.00	1	455.00	.	2002	2002	2002
Hydro, Midaz	10	10.10	0.00	100.00	0.00	6	198.33	61.71	2019	2018	2022
Morphine	6	6.06	0.00	100.00	0.00	5	206.80	50.13	2011	2010	2012
None were used	12	12.12	8.33	83.33	8.33	5	237.20	59.07	2021	2000	2022
Induction agents											
Alfax	25	25.25	0.00	100.00	0.00	20	226.50	96.27	2020	2017	2023
Alfax, Hydro, Midaz	8	8.08	12.50	75.00	12.50	3	247.67	125.87	2021	2017	2022
Isoflurane	7	7.07	28.57	71.43	0.00	2	288.50	3.54	2015	2000	2022
Ketamine	5	5.05	0.00	100.00	0.00	3	254.67	76.58	2020	2020	2022
Propofol	46	46.46	0.00	97.83	2.17	36	209.86	89.06	2004	2000	2017
Maintenance inhalants											
Isoflurane	38	44.71	5.26	94.74	0.00	25	235.88	94.72	2004	2000	2019
Isoflurane, sevoflurane	7	8.24	0.00	100.00	0.00	6	276.83	110.04	2017	2005	2020
Sevoflurane	36	42.35	0.00	94.44	5.56	30	185.37	73.84	2017	2001	2023
Maintenance Alfax or propofol CRI	20	100.00	0.00	95.00	5.00	13	218.85	67.79	2022	2019	2022
Recovery drugs											
Butorphanol	5	5.05	0.00	100.00	0.00	4	267.75	33.43	2001	2000	2009
Epi	6	6.06	16.67	83.33	0.00	3	248.33	113.17	2019	2017	2020
Norepi	11	11.11	9.09	90.91	0.00	8	255.75	121.74	2021	2017	2023
Norepi, Flumazenil	8	8.08	0.00	100.00	0.00	8	210.63	31.37	2022	2019	2022
None were used	43	43.43	2.33	93.02	4.65	31	208.10	97.45	2005	2000	2023
Recovery drugs											
Recovery agent administered	56	56.57	3.57	94.64	1.79	38	227.87	81.28	2019	2000	2023
No recovery agent administered	43	43.43	2.33	93.02	4.65	31	208.10	97.45	2005	2000	2023
All	99	100.00	3.03	93.94	3.03	69	218.99	88.78	2014	2000	2023

The number and mean ± SD of anesthesia times were also for the following categories: anesthetic cases and anesthetic category, total anesthesia time; premed anesthetics, time from premedication administration to induction; induction anesthetics, time from the onset of induction to maintenance; maintenance anesthetics, period between the onset of induction and end of anesthesia (also referred to as anesthesia duration); and recovery agents, time between the end of anesthesia and patient recovery. The median and range of years drugs were used are also reported. All values included had groups ≥ 5 individuals (**Supplementary Table S7**). Fields that contain a period indicated no data present or insufficient "n" numbers to analyze.

Alfax = Alfaxalone. CRI = Constant rate infusion. Epi = Epinephrine. Hydro = Hydromorphone. IC = Intracardial. Midaz = Midazolam. Norepi = Norepinephrine.

that underwent anesthesia received a combination of injectable and inhalant, with a recent shift to utilizing alfaxalone as a constant rate infusion (CRI) rather than inhalant as the maintenance method beginning in 2019.

In cases where a premedication was included as part of the anesthetic plan, the drugs alfaxalone, buprenorphine, butorphanol, (dex)medetomidine, hydromorphone, ketamine, midazolam, and morphine were typically used, either alone or in combination and were all injected IM (Table 2). By 2011 the use of butorphanol as a solitary premedication agent was completely discontinued. Prior to 2011, the most common premedication plan was a solitary agent, with the most common agent used being butorphanol. However, over the last decade, the data suggest that there has been a positive shift towards having multiple drugs incorporated into a preanesthetic plan. After 2017, the most popular preanesthetic plan included one where hydromorphone and midazolam were administered, often with the addition of alfaxalone.

For induction, the majority of cases relied on injectables, with propofol being the most popular choice. After 2017, protocol shifted towards utilizing alfaxalone as the primary induction agent (Table 2). Inhalants, when utilized for induction, were administered to lizards via mask or an induction chamber. All animals that entered a plane of surgical anesthesia (defined by loss of righting reflex and stimulus response) were intubated and ventilated. Animals that only underwent deep sedation were not intubated. All animals received IV or intraosseous (IO; as access allowed) Lactated ringer solution fluids at a default maintenance rate of 3 mL/kg/h, unless contraindications were present.

For maintenance anesthetics, many cases depended on the use of inhalants to keep a patient at a surgical plane of anesthesia. Of the patients maintained on inhalants only, 45% preferred isoflurane, while 42% used sevoflurane. The trend in the past decade has favored the utilization of sevoflurane over

isoflurane (Table 2). In 8% of cases, the patient would begin maintenance on isoflurane and then be shifted to sevoflurane. Lastly, 20 of the remaining cases utilized alfaxalone administered as a CRI or repeated IV boluses, with this manner of maintenance becoming much more popular in the past 5 years. Noninhalant maintenance has only recently begun to be utilized, with the first case occurring in 2019, meaning there is a low number of cases to analyze at the moment.

The portion of patients undergoing anesthesia with no overt health concerns was in the minority, with the retrospectively assigned ASA I status covering only a small portion of the patients undergoing anesthesia (21.3%) and the largest category being an ASA III (35.1%). The other ASA status percentages (retrospectively assigned) were ASA II (31.9%), ASA IV (7.4%), and ASA V (4.3%). Regarding recovery, there is a near even split of whether a recovery agent was utilized or not, with 57% utilizing some form of recovery agent and 43% not (Table 2). When examining retrospectively assigned ASA scores, there does not seem to be any notable association between the ASA status and use of recovery agents.

In these patients, the most common drug chosen was norepinephrine, followed by epinephrine, both of which were frequently administered alone IM (Table 2).

Anesthetic agents, doses, and times

Although anesthesia times for premedication, induction, maintenance, and recovery are summarized for individual anesthetic groups (Table 2), "n" numbers are low in these groups. Therefore, to evaluate anesthesia times for individual drug combinations, each individual injectable or inhalant drug used alone or in combination was assessed, and their respective doses (mg/kg) and anesthesia times (minutes; **Tables 3 and 4**) were reported. Groups that had "n" numbers ≥ 10 are discussed further here.

For premedications, focus was on the drugs alfaxalone, butorphanol, hydromorphone, and midazolam (Table 3). Alfaxalone was differentiated between a premedication or induction agent for each case based on the effects witnessed. If the patient proceeded to enter an anesthetic plane without the administration of additional follow-up drugs, the dose was considered an induction dose instead of a premedication. Alfaxalone had a mean dosage of 11.9 mg/kg with a range between 3 and 24 mg/kg, with the vast majority of cases that utilized alfaxalone as a premedication having done so via IM administration. There were 2 cases that utilized IV administration as the selected route, but there were no noticeable differences in the dosages between the 2 premedication routes for alfaxalone. However, a sample size of 2 patients is not sufficient to truly compare the differences that the route of administration makes. When given in combination with other drugs, alfaxalone produced sedation to light anesthesia lasting around 53 ± 26 minutes. The most common protocol for these 3 drugs was a combination of all 3,

Table 3—Dataset summary of injectable anesthetics used in lizards, indicating the number of cases available where dosage information and anesthetic times were both recorded accurately for anesthetic stages—premeds, induction, and maintenance. Whether a drug was injected alone or in combination is indicated.

			Drug dose (mg/kg)				Anesthesia duration (min)	
	Technique	**N**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**
Premeds								
Alfax	Combination	21	11.9	4.76	3	24	53.21	26.05
Buprenorphine	Alone	2	0.145	0.08	0.09	0.20	0.00	0.00
	Combination	1	0.020	.	0.02	0.02	40.00	.
Butorphanol	Alone	30	1.08	0.42	0.4	3.0	37.00	29.64
	Combination	1	1.90	.	1.9	1.9	37.50	53.03
Dexmed	Combination	3	0.050	0.00	0.05	0.05	42.00	15.10
Hydro	Alone	3	0.67	0.29	0.5	1.0	25.75	22.78
	Combination	34	0.45	0.11	0.1	0.6	51.51	30.20
Ketamine	Combination	5	8.0	2.69	5	10	25.20	25.36
Midaz	Combination	30	1.23	0.50	0.5	2.0	50.85	32.86
Morphine	Alone	6	1.16	0.25	1.0	1.5	37.83	15.32
	Combination	1	1.49	.	1.5	1.5	32.00	.
Induction agents								
Alfaxalone	Alone	23	8.3	4.64	1	18	17.47	27.86
	Combination	9	9.6	3.48	3	15	10.40	16.28
Opioids (butorphanol, hydro, morphine, etc)	Combination	9	0.49	0.03	0.4	0.5	10.40	16.28
Ketamine	Alone	3	6.8	2.78	5	10	2.08	4.43
	Combination	1	5.0	.	5	5	6.00	.
Propofol	Alone	44	8.5	3.49	2	15	9.22	9.70
Midaz	Combination	6	1.36	0.75	0.2	2.0	12.41	18.86
Maintenance								
Alfax or propofol CRI	Alone	6	11.9	2.41	10	15	145.25	49.85
	Combination with inhalants	7	12.7	3.88	5	15	109.10	47.13
All	All	13	12.3	3.18	5	15	125.68	49.04

Dexmed = Dexmedetomidine. Alfax = Alfaxalone. Hydro = Hydromorphone. Midaz = Midazolam. CRI = constant rate infusion. Fields that contain a period indicated no data present or insufficient "n" numbers to analyze.

Table 4—Dataset summary of inhalants used to maintain lizards under a plane of anesthesia, indicating the number of cases available where nadir and peak gas concentrations and anesthetic times were accurately recorded. Inhalants were categorized by type and whether they were used alone or in combination with other anesthetics.

		Concentration inhalant nadir (%)			Concentration inhalant peak (%)			Anesthesia duration (min)		
Maintenance type	**Maintenance inhalants**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**	**N**	**Mean**	**SD**
Inhalants	Isoflurane	31	1.71	0.76	31	3.80	1.19	31	132.03	59.41
	Isoflurane, sevoflurane	7	1.83	0.62	7	5.00	1.63	7	174.86	88.81
	Sevoflurane	25	2.17	0.74	25	5.42	1.71	24	118.83	51.43
	Unknown inhalant	2	1.75	1.77	2	3.50	2.12	2	50.00	7.07
Combination (with injectable)	Isoflurane	5	1.70	0.57	5	4.30	1.10	5	126.20	68.56
	Sevoflurane	10	1.55	0.76	10	4.22	1.78	10	117.50	51.59
	Unknown inhalant	2	2.10	1.27	2	3.75	0.35	2	121.00	38.18
Maintenance CRI combination										
Alfax	Isoflurane	1	1.50	.	1	5.00	.	1	101.00	.
	Sevoflurane	7	1.29	0.49	7	3.31	1.20	7	106.86	55.00
	Unknown inhalant	2	2.10	1.27	2	3.75	0.35	2	121.00	38.18

Alfax = Alfaxalone.

Fields that contain a period indicated no data present or insufficient "n" numbers to analyze. **Supplementary Table S8** features a species breakdown of maintenance inhalents.

with a few rare instances of differing protocol, which explains the near identical timeframes (Table 2). The dosages at which midazolam and hydromorphone were administered in combination ranged from 0.5 to 2.0 mg/kg and 0.1 to 0.6 mg/kg, respectively. Butorphanol, typically used alone, was administered at doses ranging from 0.4 up to 3 mg/kg, which resulted in a slightly shorter timeframe than the other premedication protocols, averaging around 37 ± 30 minutes before patients were induced (Table 3).

For induction, focus was on cases that involved the use of alfaxalone or propofol (Table 3). Alfaxalone was primarily used as a single induction agent and was administered between 1 and 18 mg/kg, with a mean dose of 8.3 mg/kg. When the routes of administration were compared, IM administration ranged from 2 to 13 mg/kg with a mean of 8.3 mg/kg, while IV/IO administration ranged from 1 to 18 mg/kg with a mean dose of 8.4 mg/kg. Alfaxalone when administered alone resulted in a longer induction time than when combined with other induction agents, with the difference being an average induction time of approximately 18 versus 10 minutes. The mean dosages for each of these categories are 8.3 mg/kg for solo administration and 9.6 mg/kg for administration in combination with other agents. When propofol was utilized as an induction agent, it was always the solitary agent. In reports where propofol was the induction agent, the mean dose typically administered was 8.5 mg/kg, IV/IO, with doses ranging between 2 and 15 mg/kg. This resulted in a short induction period, lasting around 9 ± 10 minutes.

For maintenance, focus was on 2 main categories: inhalant or CRI (with or without inhalant in combination). The mean total anesthesia time for isoflurane and sevoflurane, when administered alone, showed that isoflurane had a slightly longer average time (132 ± 59 minutes when compared to sevoflurane's 119 ± 51 minutes). Mean nadir and peak inhalant concentrations are as follows: nadir of isoflurane, 1.71%; nadir of sevoflurane, 2.17%; peak of isoflurane, 3.80%; peak of sevoflurane, 5.42% (Table 4). Inhalants were categorized into 2 groups—1 in which they were administered alone and 1 in which injectable anesthetics were used for induction. When combined with injectable anesthetics, mean inhalant concentrations were typically lower between the 2 groups when looking at sevoflurane. There was not a sufficient number of cases to compare the isoflurane in combination with injectables to the isoflurane alone. For sevoflurane alone, mean nadir and peak inhalant concentrations ranged between 2.2% and 5.4% but fell to around 1.6% to 4.2% when sevoflurane was combined with injectable anesthetics.

Summary of anesthesia times, patient vitals, and anesthesia outcomes

After assessing individual anesthetic groups, parameters were broadened evaluate the mean premedication, induction, maintenance, surgery, recovery, and total anesthesia times for plans that incorporated the use of either inhalants or injectables alone or employed some combination of the two for inducing and maintaining a patient under anesthesia. The combination category, where an inhalant and injectable were used, had a shorter mean recovery time (44 ± 41 minutes) when compared to the other 2 categories **(Table 5)**. The dataset was also analyzed in terms of anesthetic level (ie, sedation vs surgical). However, summarization of the combined anesthetic times for all anesthetic categories to report the average anesthesia times for all lizards within this dataset was the primary focus. A summary of patient vitals is also available but not discussed **(Supplementary Table S6)**.

Cases where a premedication was included as part of the anesthetic plan revealed that the mean time between administration and the onset of induction was 49 ± 26 minutes. For induction, 94 cases were available. The time of onset to maintenance was short, averaging around 13 ± 21 minutes, while maintenance lasted 127 ± 59 minutes amongst the 93 cases assessed. When evaluating average procedure time, 75 cases were available and showed that the average procedural duration was 91 ± 49 minutes. The mean recovery time was 47 ± 42 minutes,

Table 5—Complete dataset summary of anesthesia in lizards.

	Anesthesia times (min)																	
	Premed			Induction			Anesthesia duration			Surgical duration			Recovery			Total anesthesia		
Anesthetic category	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
Injectables	10	59.00	26.91	12	12.73	20.80	12	126.00	53.42	10	89.30	51.69	6	55.50	57.67	6	256.00	79.03
Combination	57	48.56	26.39	73	11.41	17.53	72	128.11	61.39	61	93.61	49.88	58	44.26	40.69	58	215.95	90.77
Inhalants	7	33.14	17.76	9	24.93	37.03	9	121.44	51.97	4	57.25	20.56	5	65.20	47.25	5	209.80	80.56
All	74	48.51	26.22	94	12.87	20.56	93	127.19	59.06	75	91.09	49.27	69	46.76	42.43	69	218.99	88.78

Total number of cases is broken down by anesthetic category and anesthesia level as well as the number and mean ± SD for anesthesia times (in minutes) for premed, induction, maintenance, procedure, and recovery periods. The summed total anesthesia time calculates premed (when applicable), maintenance or anesthesia duration, and recovery.

and total anesthesia time was 219 ± 89 minutes in 69 cases where this could be calculated (Table 5).

Next examination of cases where an animal died during surgery or was elected to be euthanized during an anesthetic event was performed. All cases that were euthanized utilized IV pentobarbital sodium and phenytoin sodium followed by pithing as a secondary measure. Two lizards were euthanatized due to extensive pathology identified at the time of surgery. One of these lizards was a 1-year-old male green iguana (*Iguana iguana)* whose colon was severely distended with brown fluid. The wall was multifocally thickened, and both kidneys were diffusely pale on gross examination. Histopathology showed a severe, multifocal, subacute to chronic ulcerative colitis with intralesional fungal hyphae and a multifocal, acute, necrotizing septic cholangiohepatitis. The other lizard euthanized due to identified pathology was a 14-year-old female green iguana that upon exploratory coeliotomy was discovered to be filled with extensive metastatic disease. Another lizard was deemed clinically brain-dead, defined by a continued absence of any reflexes or recovery from plane of anesthesia for an extensive period of time after removal from anesthetic agent, during the procedure and was euthanized. This lizard was a 9-year-old green iguana, and histopathology confirmed severe hepatosis. This liver failure likely caused anemia and secondarily led to the excessive blood loss and eventual brain death. The final case that resulted in death was a patient that failed to recover overnight with supportive care. This lizard, a 7-year-old female Asian water dragon (*Physignathus cocincinus*), presented with a severely increased body condition (BCS, 5/5) and numerous other clinicopathologic abnormalities. The most severe of these abnormalities included: severe hyperphosphatemia (17.2 mg/dL; reference interval, 3.4 to 8.2 mg/dL) and severe hypercalcemia (78.5 mg/dL; reference interval: 11.6 to 13.3 mg/dL). Liver changes had been identified on ultrasonography, and liver biopsy was recommended during the scheduled ovariohysterectomy. The lizard (ASA score 2) was premedicated with hydromorphone, midazolam, and alfaxalone in combination. The patient was then induced with alfaxalone and maintained on a combination of alfaxalone CRI with supplemental sevoflurane in oxygen. During anesthesia, heart rate varied between 60 and 92 beats/min, ventilation rate varied between 1 and 9 breaths/min, $ETCO_2$ ranged from 10 to 38 mm Hg, and patient SpO_2 was not recorded. Following the procedure, recovery did not progress as expected, and the patient died despite IV fluid therapy, naloxone, and flumazenil, followed by atropine and eventual doxapram while receiving manual ventilation throughout. The patient experienced severe bradycardia leading

Table 6—Summary table of the time intervals during procedures for anesthetic combinations for which n = 4 or more.

	Anesthetic combinations for groups of ≥ 5 patients														
	Premed to induction (min)			Induction to maintenance (min)		Duration of anesthesia (min)		Surgery duration (min)		Anesthesia end to extubation (min)		Recovery time (min)		Total anesthesia (min)	
	N	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Premed agents															
Alfax, Hydro, Midaz	18	59.9	25.2	17.0	32.3	148.4	68.8	102.7	62.5	51.2	48.5	51.7	48.5	259.9	96.7
Butorphanol	34	37.0	29.6	8.8	11.5	114.9	59.5	70.4	48.4	23.2	40.4	26.6	40.1	178.5	81.1
Hydro, Midaz	10	49.2	40.4	12.6	13.7	111.4	39.3	47.6	33.2	13.5	15.9	19.5	20.8	180.1	80.4
Morphine	6	37.8	15.3	8.2	7.5	109.5	36.1	66.7	40.1	39.0	27.4	39.0	27.4	186.3	67.3
None were used	12	14.0	23.1	12.3	18.6	124.2	84.7	80.5	68.9	21.1	34.1	21.1	34.1	159.3	98.8
Induction agents															
Alfax	25	51.4	24.9	17.5	27.9	118.7	65.8	76.0	55.4	30.9	36.6	33.6	36.5	203.7	98.7
Alfax, Hydro, Midaz	8	48.6	49.8	12.4	18.9	101.8	87.6	64.1	75.8	13.9	20.0	13.9	20.0	164.3	137.3
Isoflurane	7	12.4	22.6	9.6	24.4	97.9	81.7	28.1	50.3	20.1	34.4	28.9	52.6	139.1	124.1
Ketamine	5	44.4	27.0	2.1	4.4	129.0	14.1	76.8	21.4	55.0	67.6	55.4	67.5	228.8	64.7
Propofol	46	34.0	28.7	9.2	9.7	121.4	61.6	81.9	51.0	32.8	44.4	35.3	43.7	190.7	91.5
Maintenance Alfax CRI	20	40.4	29.8	18.2	31.5	119.4	55.4	82.1	52.3	33.6	41.0	33.7	41.0	193.5	76.7

Alfax = Alfaxalone. Hydro = Hydromorphone. Midaz = Midazolam. CRI = Constant rate infusion.

to the eventual cessation of the heartbeat. The heart was restarted utilizing epinephrine and multiple atropine doses. The patient was left on fluids overnight without oxygen monitoring to see whether spontaneous recovery would occur, but it did not. Necropsy was not performed on the patient; however, findings before and during the procedure were consistent with hepatopathy, which was likely a strong factor in this anesthetic death.

Discussion

Numerous anesthetic protocols have been utilized for lizards at the referral hospital throughout this 23-year period (2000 to 2023). A thorough review of these anesthetic events was conducted to evaluate vital parameters and durations to improve understanding and utilization of the best available anesthetic protocols. The results of these anesthetic episodes (2 of 104 [1.92%]) were in line with literature-reported death rates of reptiles under anesthesia at 1.49%.[21] Trends observed at the hospital mostly reflected the advancements made in lizard anesthetic research over the past 2 decades. Extra-label drug use was performed with owner consent and complied with provisions of AMDUCA and its implementing regulations[22] in relevant cases.

This retrospective study also revealed some areas that could use continued improvement. One of the challenges that referral teaching hospitals face is the inconsistent skill and experience levels of the students who are in charge of record-keeping. Due in part to the inexperience that some students have when at the beginning of their careers, it is not uncommon for some vitals or time points to be missed. The continued evolution and development of curriculum that provides better training for students has improved and will continue to do so with further developments. Within the dataset, issues were primary found in in 2 different areas. The first addressed the quality of anesthesia time records, which factors in the anesthesiologists' tracking of each individual time point. The other looked at the number of vitals monitored. Given that the dataset covers such a wide range of times, it is possible that the data are skewed by earlier shortcomings and are not representative of the current state of anesthesia records. In order to better assess whether the data are representative, trends over time were observed and it was noticed that within the past 10 years, record-keeping improved, specifically regarding patient vitals. In the categories of poor, lacking, good, and excellent as defined previously, the patient vitals trended in the direction of improvement over the years. The only exception to this trend is the 1 case that fell under the poor category for vitals; this case occurred in 2016 and skews the data, as it is the solitary poor case.

However, it was concerning to see the opposite prove true for the quality of anesthesia time records. For the anesthesia time records, it was speculated that the poor record-keeping that has developed can be attributed, at least in part, to the increased frequency of multiple procedures/diagnostics occurring under 1 anesthetic episode. The transition between the imaging area and surgical suite is a likely point where there were often missed time points for vitals. Other possible explanations for the increase in missing time points include longer total duration of anesthetic episodes, meaning more opportunity for error; increased amount of recovery drugs, which possibly indicates more complicated procedures; or a lower number of records to analyze from the earlier dates.

It was not surprising to find that when patient vitals were analyzed, the order for undocumented or unmonitored vitals was Spo_2 as the most poorly monitored, followed by $ETCO_2$ and finally temperature. The Spo_2 probes are known for their difficulty to work with and an overall lack of reliability in some reptiles. It was also predictable that $ETCO_2$ was not frequently monitored, as roughly one-third of the analyzed lizards (33) were not intubated, with patient size and anesthesia levels as the most likely contributing factors. An identified major area for improvement in vital monitoring is temperature, as 22% of cases had no temperature recorded. The temperature could prove useful not only for future research but also for predictive value of extended anesthesia times, as colder body temperatures have been linked with reduced metabolism of anesthetic agents in reptiles.[23] All animals were provided external heating with a warm pad, which is an unspecific way to provide heat.

Many factors likely contribute to the development of poor records, and it will likely take many changes to see significant improvements. Three major areas that could offer improvement include anesthesia sheets with necessary data for research given appropriate fields, a more optimized transition process between diagnostics and procedures with a dedicated individual only keeping records, and the eventual implementation of automated record-keeping with printouts from the machines reading the vitals. The implementation of automated printouts is a longer-range projection but definitely a strong possibility.

The anesthesia sheets themselves could do with a research-oriented redesign because during certain years, there is no space for an ASA status, and oftentimes drug details such as times and quantities administered are scribbled illegibly in the corner of the sheet to avoid grabbing another sheet. The lack of designated sections for information coupled with the amount of excess free space leads to a wide discrepancy in the quality and quantity of data recorded, making retrospective analysis challenging. We recommend that anesthesia sheets be redesigned in a way that reduces the amount of variance between the users by (1) providing designated sections for each category deemed important, (2) providing a final drug sheet for people to write all the appropriate information after the procedure is complete, and (3) providing predetermined categories for sections such as anesthetic depth.

Regarding anesthetic trends, propofol was the most popular choice for induction, followed closely by isoflurane. Isoflurane was the most popular agent for maintenance of anesthesia, followed closely by sevoflurane, which was often combined with an injectable. In recent times, there has been an increase

in the usage of alfaxalone both as an induction agent and as a CRI for maintenance. Previous studies in lizards using inhalants have determined that the minimum anesthetic concentration to prevent movement in 50% of patients for isoflurane is 1.8% and for sevoflurane is 3.1%.[24] It is important to note that these data were studied only in green iguanas and were of a small sample size (6 lizards). This means that they may not translate to all lizard species. The findings from anesthetic episodes reviewed here showed that using either inhalant in combination with an injectable led to a similar total anesthesia time with lower concentration or a quicker recovery time with the same concentration, both of which are expected and desirable results. The trend noted of sometimes switching from isoflurane to sevoflurane can be explained by sevoflurane being less soluble than isoflurane, which can result in somewhat faster onset and recovery times. Another potential benefit is that the ability to change the inhaled concentration is quicker with sevoflurane than isoflurane. The utilization of sevoflurane in lizards may lend itself to faster recovery times due to these factors, which led to a choice to shift patients to sevoflurane at times.

Review of the dataset showed that these patients' recovery times fell within the range of those specified in other publications involving reptiles, where the mean recovery time ranged between 46 and 289 minutes.[15,25,26] These data are of limited value, though, as only 7% of the usable recovery times were inhalant alone. The finding that recovery in lizards is over triple the high end of nonreptilian species (65 vs 20 minutes) is unsurprising, as it is well known that reptiles tend to have reduced heart and respiratory rates along with slower metabolisms that can be slowed even more by lower temperatures, all of which affect drug distribution and elimination. Other factors that might contribute to these differences include the difficulty in identifying preexisting liver and kidney disease in reptiles or subjective differences in identifying lizard stages of recovery. The use of recovery agents in lizards should be considered in any anesthesia plan to enhance recovery time. The use of reversible anesthetic agents and their corresponding reversal agent is also advised for finer control of anesthesia.[27]

In cases where injectable anesthetics were used, certain agents were phased out over time, including butorphanol (last used in 2011), buprenorphine (a single usage in 2018, with last usage before being in 2010), and morphine (last used in 2012). The trend of morphine being phased out in usage correlates with the increase in usage of hydromorphone as a replacement as the opioid of choice at the institution. The single usage of buprenorphine in 2018 in spite of literature suggesting little analgesic efficacy in reptiles is not fully explained, but may be attributed to the nationwide opioid shortage that was ongoing in 2018.[28] Alfaxalone has been the dominant forerunner as an anesthetic agent in part due to its versatility. Alfaxalone is versatile not only in route of administration but also in usage, being implemented successfully as part of protocols for premedication, induction, and maintenance. Alfaxalone as a maintenance agent has 2 primary methods: multiple dosing and CRI. The current trend favors CRI over multidosing, likely due to the consistency of effects and close control on quantities given. Recent studies have shown that there is similar efficacy in the administration of SC versus IM alfaxalone.[29] If IV or IO access is impossible, thereby limiting CRI use, the similar efficacy in route of administration may increase preference for utilizing the SC route to decrease associated patient pain and discomfort. There may be compounding factors to consider when utilizing an SC route of administration. Patient/pharmacologic factors to consider include the impact that potential hypothermia and hypotension may have on drug uptake. A mechanical factor to consider is that SC administration is not easy to titrate under anesthesia. These factors may create difficulties for SC administration under anesthesia, but do not impact the efficacy of this route for premedication.

An overarching look at the dataset reveals that the provided ASA status was often lower than a retrospective ASA status assigned after procedures. Higher ASA status is generally associated with prolonged anesthesia times, as the factors that cause higher ASA status are often indicators of compromised systemic health. Therefore, clinicians are advised to perform a detailed preanesthesia physical examination and perform bloodwork to see any abnormalities that may indicate potential medical compromise.

As with most retrospective studies, limitations of the present study included human error, particularly regarding the accuracy or the lack of information on medical and/or anesthesia reports. The changing of the anesthesia document utilized by the university may also have skewed some values. The lack of a universal BCS for lizards and the subjectivity in scoring BCS and ASA are also weak points. Given the low numbers of anesthesia-related deaths, no links to increased mortality risk were identified. Outliers in the data were also not excluded, which may impact reported mean values.

In conclusion, this report details the largest number of anesthetic events in lizards and provides useful information for clinicians regarding current trends and the need for greater uniformity in the assessment of lizard BCS and ASA. This study also identified the need for bloodwork and temperature monitoring to evaluate possible determining factors for anesthetic metabolism. It is suggested that anesthesia sheets be created in a way that removes as much subjectivity as possible and allows for easy utilization for retrospective research. These suggestions are specifically for the University of Georgia Veterinary Teaching Hospital, but may apply to other institutions as well and should prompt a more thorough review of institutional protocols.

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Supplementary Materials

Supplementary materials are posted online at the journal website: avmajournals.avma.org.