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Reptiles: Aquatic Turtles (Chelonians) (15-Mar-2001)

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Introduction

This chapter highlights the anesthetic management of two diverse groups of aquatic chelonians: the endangered, large, marine turtles (Table 1) and the numerous species of smaller, fresh water turtles. Of the latter species, the red-eared slider (*Trachemys scripta elegans*), painted turtle (*Chrysemys picta*), and musk turtle (*Sternotherus odoratus*) are frequently kept as household pets.

Table 1. Common and scientific names and weights for sea turtle species.

Scientific name	Common name	Maximum weight lbs (kg)
Caretta caretta	Loggerhead	Up to 450 (205)
Chelonia agassizii	Black turtle	No data
Chelonia mydas	Green turtle	500 (227)
Dermochelys coriacea	Leatherback	Up to 1,300 (591)
Eretmochelys imbricata	Hawksbill	175 (80)
Lepidochelys kempi	Kemp's Ridley	100 (45)
Lepidochelys olivacea	Olive Ridley	100 (45)
Natator depressus	Flatback	No data

Patient Handling

Concerning sea turtles, the caretaker must be cognizant of the dangers of the turtle's bill. The turtle's jaw muscles are powerful and a bite can cause severe damage. If the turtle is free swimming, a pole can gently guide the turtle's head away from the handler and direct the turtle into a shallow area of the tank for capture. The turtle should be approached from the side or rear and held by its carapace behind both fore flippers.

Most of the common fresh water turtles can be restrained manually without much danger due to their small size. However, caution should be exercised as some (i.e., the red-eared slider and painted turtle) will readily bite. Consequently, handling these turtles is less hazardous if they are caught by the rear of the carapace. Matamata (*Chelus simbriatus*) and snapping turtles (*Chelydra serpentina*) are aggressive with dangerous bites so they should be handled with extreme caution. For these, the handler can lift the turtle by grasping the base of the tail with one hand and slipping the other hand under the plastron for support (Fig. 1). Sometimes a plastic cup can be placed over the turtle's head to deter biting. For both species, the handler should also be aware that there is a zoonotic potential for salmonellosis when handling turtles.

Figure 1. Proper support and restraint for dangerous chelonians such as the snapping turtle (*Chelydra serpentina*). - To view this image in full size go to the IVIS website at www.ivis.org . -

Preanesthetic Management

A complete history, physical examination, and blood sample analysis should be completed prior to anesthesia. Careful observation of the unrestrained turtle in its own habitat can determine the resting respiratory rate, overall activity level, and

physical condition. If the turtle is swimming, altered buoyancy may suggest a respiratory or gastrointestinal disorder (i.e., pneumonia or foreign body). Breathing patterns in aquatic turtles are characterized by a ventilatory period of multiple breaths followed by a non-ventilatory period of apnea. For example, the overall respiratory rate for swimming loggerhead sea turtles (n=5) is 0.3 breaths/min but the rate during their ventilatory phase is 3 breaths/minute followed by non-ventilatory periods of up to 16 minutes [1]. Similarly, resting green sea turtles may have an overall respiratory rate of 0.5 to 0.7 breaths/minute but this rate includes non-ventilatory phases that last from 1 to 10 minutes [2]. Consequently, counting the respiratory rate for a longer period of time, 15 - 20 min, may provide a more accurate value.

The turtle must be weighed pre-operatively for accurate drug administration. The weight and carapace length can be compared to reference ranges to further estimate age and physical condition [3-5]. Prior to anesthesia, the head, neck, and carapace can be scrubbed lightly to remove adhering material such as algae and barnacles.

Weighing should be followed by a thorough physical exam [6]. A resting heart rate can be obtained by placing a Doppler flow probe at the thoracic inlet or the femoral fossa. A cloacal temperature should be obtained since a turtle's metabolic state will determine normal cardiopulmonary parameters and is highly dependent upon temperature. To promote a normal metabolic rate, the turtle should be warmed to its preferred optimal temperature prior to surgery whenever feasible. The optimal temperature varies with species but most of the common turtles require a temperature between 21 - 26.7^{0}C (70 - 80^0 F). The optimal temperature for the red-eared slider is 22.2 - 30^0 C (72 - 86^0 F), for the painted turtle is 22.8 - 27.8^0 C (73 - 82^0 F), and for the musk turtle is 20 - 25^0 C (68 - 77^0 F) [7]. The optimal temperature range for marine turtles is approximately 25 to 30^0 C (77 - 86^0 F) [8]. It may take hours to days to reach the optimal temperature in some species and hence this goal may not be possible in all situations. However, maintaining a turtle at its preferred optimal temperature zone will decrease anesthetic recovery time, improve the function of the immune system, and promote healing.

It is debatable whether or not aquatic turtles should be fasted prior to anesthesia. In chelonians, several days are required for the gastrointestinal tract to be emptied and this may cause an undesirable negative energy balance to occur prior to surgery. However, ingesta may interfere with the surgery or with ventilation. Both fasting (for 12 hr in healthy Kemp's Ridley sea turtles, [9]) and non-fasting (in clinically diseased fresh water turtles) have been done by these authors without any apparent untoward consequences. Thus, the need for, proper duration of, or actual metabolic effects of fasting are unknown and recommendations cannot be made currently.

Blood Sampling

Although blood sampling can be difficult in chelonians, a pre-anesthetic sample is advisable and should be compared to normal hematologic and chemistry values (Table 2 - Table 5). Within species, normal values may vary with geographical location of the turtle, age, sex, and activity. When collecting blood, no more than 1% of the turtle's body weight should be removed or iatrogenic hypovolemia may ensue. Plasma is favored over serum for most analytical tests [3] and lithium heparin is the preferred anticoagulant for hematologic studies [3,10]. Due to species diversity, no single venipuncture technique is likely to be successful in all species or for all size turtles within the same species. Besides the venipuncture sites described below, other sites include the brachial vein, the dorsal or ventral coccygeal veins, and cardiocentesis, [11,12].

For marine turtles, the paired dorsal cervical sinuses are the most common locations for obtaining venous blood samples (Fig. 2). Each sinus is located 0.5 - 1 cm lateral to dorsal cervical midline and become larger as they approach the carapace. The turtle is restrained such that the head is pulled forward and down, below the level of the plastron, to facilitate gravitational filling of the sinuses with blood. Alternatively, the turtle can be restrained on a slanted table (Fig. 3).

Figure 2. Dorsal cervical sinus as site of blood collection from a Kemp's Ridley sea turtle (*Lepidochelys kempi*) (photo courtesy of Dr. Owens, with permission). - To view this image in full size go to the IVIS website at www.ivis.org . -

Figure 3. Restraining table for blood collection from *Caretta caretta* (photo courtesy of Dr. Owens, with permission [42]). - To view this image in full size go to the IVIS website at www.ivis.org . -

The needle is angled perpendicular to the dorsal surface of neck and advanced 1 - 3 cm deep while applying gentle suction to the attached syringe. If the sinus is not located, the needle should be removed and a second attempt made more laterally to the first. If multiple samples are required, the head must be released periodically so the animal can breathe in its normal head-up position. This technique may not be successful in particularly small turtles (hatchlings less than 100 g) or in adult males. The site may also be used for intravenous catheter placement [13] and administering anesthetic drugs. In comparison to fresh

water turtles (below), the jugular veins in sea turtles are more tortuous, thin-walled, and buried below a thick layer of fat and connective tissue; making them less than ideal sites for percutaneous venous blood sampling.
For fresh water turtles, two useful venipuncture sites are the jugular and subcarapacial veins. The jugular veins course from the tympanum to the base of the neck. They are present more laterally than in mammals and are visible midway between dorsal and ventral midline. Collecting blood from an awake turtle can be challenging, as the holder must keep the turtle's head fully extended. Thus sampling is easier if the turtle is sedated or anesthetized. In some instances, a surgical cut-down may be necessary to expose the vein.
Another common venipuncture site in fresh water turtles is the subcarapacial vein. A needle is positioned on midline at the junction of the skin and the carapace with the needle tip at a -45 degree angle (Fig. 4) and slowly advanced towards the dorsal edge of the vertebral body while applying gentle suction to the syringe. The vein is entered where the first vertebra is fused to the carapace.

Figure 4. Subcarapacial vein as site of blood collection in a snapping turtle (*Chelydra serpentina*). - To view this image in full size go to the IVIS website at www.ivis.org . -

Anesthetic Techniques
Local anesthetic techniques - because adverse physiological changes can occur with sedation or general anesthesia in even apparently healthy aquatic turtles [9,27], a local anesthetic might be an acceptable alternative method of providing anesthesia. While the toxic dose of local anesthetics in turtles is unknown, they (e.g., 2% lidocaine) have been used to infiltrate surgical cut-down sites for vascular catheter placement [15] as well as for simple procedures such as esophagostomy tube placement and laparoscopic examinations (Dr. Owens, personal communication).
Injectable anesthetic drugs - (Table 6 - Table 7)most injectable drugs are administered intramuscularly (IM) into the biceps, triceps, or quadriceps, intravenously (IV), or intracoelomically (ICo). For marine turtles, the dorsal cervical sinus can be used and is similar, but not identical, to an IV port. The primary concern with a cervical sinus drug injection is the unknown rate at which the anesthetic will be circulated. Mechanisms that regulate cervical sinus blood flow are unknown and variations in blood flow may account for the erratic onset, duration, and degree of anesthesia observed when this site is used [28, Dr.Stabenau, personal communication]. Hence, if the desired effect is not achieved after one or two injections, one should not continue to redose because of the potential for an anesthetic overdose. Drugs with a narrow margin of safety may be particularly dangerous and barbiturates, in particular, have caused a number of anesthetic deaths in sea turtles [28, Dr. Stabenau, personal communication].
Ketamine has replaced barbiturates as the more popular drug for aquatic turtles because of its supportive cardiovascular profile and larger margin of safety. The doses vary depending on factors such as the level of sedation desired and the turtle's body temperature. Ketamine, by itself, can be used for procedures that require only light sedation (physical exam, venipuncture, etc.) or for induction of general anesthesia prior to an inhalant anesthetic gas. Higher doses will provide deeper anesthesia and better muscle relaxation but have the disadvantage of a prolonged recovery. Therefore, ketamine can be combined with other anesthetic drugs to improve muscle relaxation and to obtain a deeper plane of anesthesia that is more suitable for major surgical procedures (Table 7). Similar to ketamine, tiletamine-zolazepam HCl (Telazol®) has been used in fresh water turtles. It should not be used for surgical procedures alone but can provide deep sedation for manipulations or as an induction drug. Respiratory depression can occur at the higher doses.
Benzodiazepines, butorphanol, and medetomidine HCI all have been used alone for sedation or analgesia (butorphanol, metdetomidine HCI) and can be reversed with flumazenil, naloxone, or atipamezole HCI, respectively. They are also frequently used in combination with ketamine.
If an intravenous route is accessible, propofol can be used for induction of anesthesia followed by either intermittent boluses or a constant rate infusion to maintain general anesthesia. Since prolonged apnea may ensue, the ability to provide manual ventilation is essential. Recovery is more prolonged in reptiles than in mammals, but appears more rapid than the other injectable anesthetics.
Some soft shell aquatic turtles possess an amphibian-style mode of gas exchange in which gas may diffuse across nonpulmonary surfaces (e.g., skin) [29]. For these turtles, tricaine methane sulfonate (MS-222, Sigma Chemical Co., St. Louis, MO or Finquel®, Argent Chemical Laboratories, Redmond, WA) can be used as either an injection or an immersion anesthetic. ICo injections of MS-222 (250 - 500 mg/kg) followed by immersion (1 gm/L) provided safe, surgical anesthesia for Spiny and Florida soft-shell turtles (*Apalone apinifera*, *Apalone ferox*) [29] while the dose for red-eared sliders is 250 mg/kg ICo [30].

Table 2. Presumptive normal mean (range) acid-base, arterial blood gas, and cardiopulmonary measurements in conscious, resting marine turtles at 25 - 30°C. Blood gases were taken during ventilatory periods whenever possible.

	Value	Species	Ref
Heart rate (beats/min)	(24 - 51) 34 (14 - 50)	*C. mydas* *L. kempi*	[14] [9]
Systolic/diastolic blood pressure (mm Hg)	39/30 46/39+	*C. mydas* *L. kempi*	[14] [9]
pH	7.63† 7.45 - 7.47 7.45* - 7.55+	*C. caretta* *C. mydas* *L. kempi*	[1] [14,15] [16][9]
PO_2 (mm Hg)	107† 64 - 76 86 (74 - 100) +	*C. caretta* *C. mydas* *L. kempi*	[1] [14,15] [9]
PCO_2 (mm Hg)	17† 38 - 46 30* - 43+	*C. caretta* *C. mydas* *L. kempi*	[1] [14,15] [16,9]
Bicarbonate (mM)	24.8 36.3 30+ - 32.6*	*C. caretta†* *C. mydas* *L. kempi*	[1] [15] [16,9]
Lactate (mM)	0.45 0.7* - 1.0+	C. mydas L. kempi	[14] [16,9]

*cervical sinus venous blood, +18 hrs post-anesthetic, †swimming

Table 3. Presumptive normal mean (range) hematological values for marine and fresh water turtles.

	Sea Turtles			Fresh Water Turtles		
	Value	**Species**	**Ref**	**Value**	**Species**	**Ref**
Hematocrit (%)	25 - 40 29+ - 31* 22 - 45 39 31 -34	*C. caretta* *C. agassizii* *C. mydas* *D. coriacea* *L. kempi*	[1,3,8,17,18] [10] [14,19,20] [21] [16,17,22]	19.8 26	*C. spicta* *T. scripta elegans*	[23] [24]
White cell count (x 10^3 /ul)	3.8 - 3.9 2.4+ - 5.3* 3.2 (2.0 - 3.9) 7.6 (5.7 - 9.5)	*C. caretta* *C. agassizii* *C. mydas* *L. kempi*	[3,17] [10] [19] [17]	6.66	*C. spicta*	[23]
Red cell count (x 10^5 /ul)	4.3# - 4.8* 3.4 (2.5 - 5.7)	*C. agassizii* *C. mydas*	[10] [19]	5.7 2.57 - 8.35	*C. spicta* *T. scripta elegans*	[23] [24]
Reticulocytes (x 10^3 /ul)	19.4 (8 - 30)	C. caretta	[3]			
Thrombocytes (x 10^3 /ul)	46 (30 - 60) 36 per 100 WBC	*C. caretta* *C. mydas*	[3] [19]			
Total protein (g/dl)	1.6 - 4.8 5.1	*C. caretta* *C. mydas*	[3,8,17] [20]	2.4 3.6	*C. spicta* *T. scripta elegans*	[23] [24]

WBC = White Blood Cells, * females or nesting females, # females at sea, + males

Inhalant anesthetic drugs - (Table 8) to avoid some of the complications associated with injectable anesthetics (variable uptake, prolonged recoveries, muscle damage at the injection site), some clinicians prefer to induce or maintain general

anesthesia with an inhalant anesthetic. Successful use of inhaled anesthetics requires adequate ventilation for drug uptake and thus manual or mechanical ventilation must be provided. Induction can be by injectable anesthetic drugs or by a mask technique. With a mask induction, a long induction time is likely because of the slow respiratory rate and the turtle may breath-hold. Induction times may be reduced slightly by slowly, gently "pumping" the forelimbs forwards and backwards to induce respiration and thus improve uptake of the inhalant gas. Alternatively, an "awake" intubation technique will reduce the induction time even further and can be performed on the larger marine turtles [9]. Awake intubations are not recommended in fresh water turtles.
If an awake intubation is planned for a marine turtle, two polyvinylchloride rods can be used as mouth gags to permit manual opening of the glottis with the tip of the endotracheal tube (Fig. 5).

Figure 5. Awake intubation technique in a Kemp's Ridley sea turtle (*Lepidochelys kempi*). - To view this image in full size go to the IVIS website at www.ivis.org . -

Strong laryngeal sphincter muscles can make opening the glottis difficult but patience and gentle manipulation will result in a successful intubation. The authors (PM) have attempted succinylcholine chloride (0.5 mg/kg IM) in a small number of Kemp's Ridley sea turtles but this did not appear to facilitate the intubation. Either a higher dose of succinylcholine or, perhaps, topical local anesthetic sprayed on the arytenoids would have been beneficial. Once intubated, the turtle is connected to the anesthetic circuit and hand-ventilated with the inhalant anesthetic until the turtle's general movement ceases and its palpebral reflex slows. One of the polyvinylchloride rods is removed and the endotracheal tube inserted through a hole in the second rod (Fig. 6). This rod will protect the endotracheal tube and prevent airway occlusion.

Figure 6. Method for protecting the endotracheal tube in a Kemp's Ridley sea turtle (*Lepidochelys kempi*). - To view this image in full size go to the IVIS website at www.ivis.org . -

Isoflurane is the inhalant anesthetic of choice. Sevoflurane also has been used safely in chelonians but is currently expensive. Although various types of carrier gases have been used successfully [9], it is unknown what carrier gas is most beneficial. As oxygen tensions increase, ventilation is depressed in chelonians and thus it is possible that a high-inspired oxygen concentration during anesthesia may promote a more prolonged recovery. However, intraoperative hypoxemia, possibly due to cardiovascular shunting, can occur in even healthy turtles [9] and thus we recommend a 100% inspired oxygen concentration for turtles that are positioned in dorsal recumbency or that are anesthetized for a prolonged period of time.

Table 4. Presumptive normal mean (range) electrolyte values for several species of marine and fresh water turtles.

	Sea Turtles			Fresh Water Turtles		
	Value	**Species**	**Ref**	**Value**	**Species**	**Ref**
Calcium (mmol/L)	1.3 - 1.95 1.7 - 1.85	*C. caretta* *L. kempi*	[8,25] [17,22]	2.16	*C. picta*	[23]
Chloride (mmol/L)	107 - 115 112 - 115	*C. caretta* *L. kempi*	[8,17,25] [16,17,22]	93 81	*C. picta* *T. scripta elegans*	[23] [24]
Phosphorous (mmol/L)	11.9 - 3.3 2.2 - 3.1)	*C. caretta* *L. kempi*	[8,17] [17,22]			
Magnesium (mmol/L)	0.5 - 0.9 1.5	*C. caretta* *L. kempi*	[25] [22]			
Potassium (mmol/L)	3.2 - 3.8 1.5 3.4 - 6.3	*C. caretta* *C. mydas* *L. kempi*	[8,17,25] [20,25] [16,17,22]	3.1 4.1	*C. spicta* *T. scripta elegans*	[23] [24]
Sodium (mmol/L)	140 - 157 158 141 - 155	*C. caretta* *C. mydas* *L. kempi*	[8,17,25] [20,25] [16,17,22]	130 121	*C. spicta* *T. scripta elegans*	[23] [24]
Osmotic Pressure (mm Hg)	321 320 - 370	*C. caretta* *C. mydas*	[25] [20,25]			

Table 5. Presumptive normal mean ± SD or (range) serum chemistry values for several species of marine and fresh water turtles.

	Sea Turtles			Fresh Water Turtles		
	Value	**Species**	**Ref**	**Value**	**Species**	**Ref**
BUN (mmol/L)	33 - 68 5 26 - 53	*C. caretta* *C. mydas* *L. kempi*	[8,20] [20] [8,17,22]			
Cholesterol (mmol/L)	8.6±3.1	*L. kempi*	[22]			
CK (U/L)	1680 - 3738 1225 - 1299	*C. caretta* *L. kempi*	[8,17] [17,22]			
Creatinine (**m**mol/L)	35.4± - 17.7	*L. kempi*	[22]			
Glucose (mmol/L)	5.551 - 6.88 6.33 6.2 - 6.4	*C. caretta* *C. mydas* *L. kempi*	[8,17] [20] [17,22]	4.7 3.9	*C. spicta* *T. scripta elegans*	[23] [24]
ALT (U/L)	3.9±4.1	*L. kempi*	[22]			
AST (U/L)	285 178 145±42	*C. caretta* *C. mydas* *L. kempi*	[8] [20] [22]	152	*C. picta*	[23]
Alk Phos (U/L)	53 U/L 43 89±57	*C. caretta* *C. mydas* *L. kempi*	[8] [20] [22]			
Lipase(U/L)	25±52	*L. kempi*	[22]			
Amylase(U/Ll)	665+182	*L. kempi*	[22]			
Total Bilirubin (**m**mol/L)	1.71±0.86	*L. kempi*	[22]			
Albumin (gm/L)	13 15 13±3	*C. caretta* *C. mydas* *L. kempi*	[8] [20] [22]			
Triglycerides (mmol/L)	1.39±0.90	*L. kempi*	[22]			
Uric Acid (**m**mol/L)	89 - 475	*C. mydas*	[26]	71 59	*C. picta* *T. scripta elegans*	[23] [24]

ALT = Alanine aminotransferase, Alk Phos = Alkaline phosphatase, AST = Aspartate aminotransferase, BUN = Blood urea nitrogen, CK = Creatine kinase.

Table 6. Injectable anesthetic drugs used in marine turtle species.						
Anesthetic	**Dose (mg/kg) Route**	**Induction (min)**	**Duration (min)**	**Recovery (hrs)**	**Comments**	**Ref**
Na Pentobarbital*	10 - 26 IV	14 - 120	40 - 240	4 - 24	n=8, *C. mydas*	[28]
Na Pentobarbital*	18 - 20 IV				n=5, *C. Caretta*	[1]
Na Thiopental †	18.8 - 31.4 IV	5 - 10	5 - 120	<6	n=26, *C. mydas*	[28]
Ketamine HCl	15 - 18 ml/kg IV				n=3, *C. Caretta*	[31]
Ketamine HCl	18 - 23 ml/kg IV				n=8, *C. Caretta*	[32]
Ketamine HCl †	38 - 71 ICo, IV, IM	2 - 10	2 - 10	<4	n=11, *C. mydas*	[28]
Ketamine HCl Acepromazine	No doses, IV	1 - 15 min		2.5	n=1, *L. kempi*	[33]
Ketamine HCl †† Medetomidine	2.5 IV 0.015 IV				n=1, *L. kempi*	[34]
Ketamine HCl ‡‡ Medetomidine	3 IV 0.03 IV				n=1, *L. kempi*	[34]
Ketamine HCl Medetomidine**	5 IV 0.050 IV	8.8	110 - 325	5 - 1124	n=6, *C. caretta*	[13]

IV = intravenous or cervical sinus, IM = intramuscular, ICo = intracoelomic, *1 turtle not anesthetized, †3 died while 4 never deeply anesthetized, ‡Some turtles not deeply anesthetized, **Induction followed by Sevoflurane. Atipamezole (0.25 mg/kg IV) to reverse medetomidine, ††Sedation, ‡‡General anesthesia.

Table 7. Injectable anesthetic drugs used in fresh water turtles.				
Drug	**Dose (mg/kg) Route**	**Induction (min)**	**Recovery (min)**	**Ref**
Ketamine	22 - 44 IM, SC	15 - 45	20 - 45	[35]
Ketamine	55 - 88 IM, SC		Prolonged	[35]
Tiletamine - Zolazepam	4 - 5 IM, SC			[35]
Ketamine HCl Diazepam**	20 - 60 IV, IM 2 - 5 IV, IM			[36]
Ketamine HCl Midazolam**	20 - 30 IV, IM 2 IV, IM			[36]
Ketamine HCl Medetomidine**	10 - 30 IV 0.1 - 0.3 IV, IM			[6]
Ketamine HCl Butorphanol**	10 - 30 IM 0.5 - 1.5			[36]
Ketamine HCl Propofol**	25 - 30 IM 7 IV*	0.5 after propofol	30 - 50 after propofol	[37]
Midazolam	1.5 IM			[27]
Butorphanol	0.4 - 1.0 IM, SC			[36]
Propofol	5 - 15 IV	1 - 5	30 - 45	[38]

IM = intramuscular, IV = intravenous, SC = subcutaneous, *administered 90 min after ketamine.

Table 8. Inhalant anesthetics and mean (range) duration of induction, surgery, and recovery when used in marine turtles.							
Anesthetic	**Induction Dose**	**Maintenance**	**Induction (min)**	**Surgery (min)**	**Recovery (min)**	**Comments**	**Ref**
Halothane	2-3% V*				5 - 60	n=5, *C. mydas*	[14]
Isoflurane	4-5 % V†	3.4 % ET	7	130 (75-30)	240 (92 - 452)	n=14, *L. kempi*	[9]
Isoflurane					120-360	*C. mydas*, *C. caretta*	[39]
Isoflurane	4 % V‡	3.5-4 % V	110	No data	18 hrs	*C. mydas*	[40]
Sevoflurane	injectables	0.5-2 % V				*C. caretta*	[13]

ET = end-tidal concentration (%), V = vaporizer setting (%), * Carried in 29 %O_2 & 71 %N_2, †awake intubation, ‡mask induction.

Intraoperative Anesthetic Management

Anesthetic depth - a chelonian in a light plane of anesthesia will have intact papillary, palpebral, and corneal reflexes and will respond to a skin pinch by withdrawing its limbs and neck. At deeper anesthetic planes, the extremities, head, and neck become flaccid. Once a turtle is in a deep surgical plane of anesthesia, the effects of all anesthetic drugs, including inhalants, appear prolonged compared to equivalently anesthetized mammals. Thus, to shorten the recovery phase, inhalant gas concentration should be decreased as soon as possible and generally before the end of the procedure. If the corneal reflex is lost or anesthetic depth cannot be determined, the inhalant gas should be discontinued immediately, as the patient may be too deeply anesthetized. In most situations, the surgery can proceed uninterrupted despite discontinuing anesthetic delivery. Since the eyes may remain open throughout the procedure, a topical eye lubricant should be administered to prevent corneal drying.

Cardiovascular monitoring - one of the unique characteristics of aquatic turtles that make anesthetic monitoring a challenge is their ability to have a cardiopulmonary response to anesthetic manipulations (e.g., apnea and bradycardia) similar to a normal dive reflex [21] It is currently unclear whether or not aquatic turtles undergo an actual "dive reflex" and thus it is difficult to interpret intraoperative cardiopulmonary measurements. Heart rates in awake turtles, for example, may decrease due to this "dive" reflex but may also decrease due to a decrease in temperature, surgical manipulation, or an extremely deep plane of anesthesia. Thus, the heart rate and respiratory rate from conscious, sedentary turtles is probably the best goal for which to strive while the turtle is anesthetized since oxygen requirements under anesthesia most closely approximate those of a non-active animal. If the turtle is at its preferred optimal temperature, then the predicted heart rate based on allometric scaling is calculated from the equation: heart rate = 33.4 (kg body wt) $^{-0.25}$. Actual heart rate and direct blood pressure measurements are provided in Table 3 for some marine turtles. For the painted turtle, the standard reported heart rates are 22 - 25 beats/min (25 ^{0}C) and, for the red-eared slider, are 25 - 29 beats/min (20 ^{0}C), 34 - 61 beats/min (30 ^{0}C) and 70 beats/min (35 ^{0} C) [41]. There are many methods for assessing the turtle's heart rate. Heart rate is best monitored using an ultrasonic Doppler flow probe with the crystal placed over the femoral triangle or thoracic inlet. Alternative sites for the crystal include directly over the carotid artery, the caudodorsal aspect of the front flipper, directly over the dorsal cervical sinus, or directly on the cornea. Electrocardiogram limb leads can be attached to the limbs or the axillary and femoral regions with clips, needles, or pregelled, self-adhering electrode pads. In some species, the surface voltages will be small with these lead configurations and placement of the cranial leads on the neck and caudal leads to the forelimbs may be more worthwhile. Normal Lead II electrocardiogram pattern in turtles will have small upright P waves, large R waves, long QT intervals and small upright T waves [42].

A pulse oximeter may be a useful, but inconsistent, monitor to assess heart rate and oxygenation. A pediatric probe may be attached to a tongue or distal aspect of a limb but the pigmented limbs and short, fleshy tongues of fresh water turtles may prohibit obtaining an accurate reading from these species. Consistent signals also were not obtained when finger probes were placed on the flipper region of anesthetized Kemp's Ridley sea turtles, either because of poor pulsatile flow or the extremely slow heart rate [9]. In some cases, a rectal probe may be more useful. Oxygen saturations of 87 to 94% were reported in one case report of an anesthetized Kemp's ridley sea turtle [33], but these values were not compared to simultaneous arterial oxygen tensions so it is unclear if the values are representative of true hemoglobin saturation.

Finally, an esophageal stethoscope may be useful to monitor heart rate in fresh water turtles but is not helpful in marine

turtles as the keratinous esophageal protrusions seems to prevent placement of the stethoscope past the pharyngeal region.
Respiratory monitoring - turtles lack a muscular diaphragm and actively must recruit muscles on both inspiration and expiration to achieve ventilation. For this reason, many turtles breathe spontaneously by extending their head and neck up and forward while thrusting their forelegs backwards to encourage air movement into their lungs. For the anesthetist, this muscle activity will be lost during anesthesia and mimicking this activity by manually moving the turtle's limbs back and forth may induce some degree of ventilation (and thus the uptake or removal of inhalant anesthetics). For longer procedures, the turtle should be intubated and some method of providing controlled ventilation is required.
If mechanical ventilation is desired, one ventilator that provides an adequate range of settings is the Vetronic Services Ventilator (Bioanalytic Systems, Inc., 1-800-654-6327, Fig. 7). However, the ideal respiratory rates, tidal volumes, inspiratory pressures, and flow rates for supporting ventilation are not clearly defined. Tidal volumes from awake turtles are highly variable and are influenced by species, whether the turtle is in water or on land, its body position, and its temperature. Variations in tidal volumes can range from 4 to 14 ml/kg for the leatherback sea turtle, 33 to 49 ml/kg for the loggerhead sea turtle, and 24 to 187 ml/kg for the green sea turtle [21].

Figure 7. Vetronic Services Ventilator. (photo courtesy of Dr. Divers, with permission). - To view this image in full size go to the IVIS website at www.ivis.org . -

These tidal volumes are much greater than for most fresh water turtles (e.g., 6.9 ml/kg for the red-eared slider) [21]. The effect of dorsal or ventral recumbency for surgical positioning will greatly affect a turtle's tidal volume. The lung compliance is much greater (and thus tidal volumes) in dorsal recumbency. For example, the tidal volumes of green sea turtles in dorsal recumbency ranged from 50 - 100 ml/kg but decreased to 25 - 32 ml/kg when turtles were placed in sternal recumbency [2]. In general, tidal volumes are considered adequate when the front limbs move outward slightly during inspiration. For respiratory rate, one should strive for the preoperative respiratory rate bearing in mind that awake turtles tolerate great periods of apnea. Sea turtle dives range between 9 to 30 minutes in duration and can extend up to 60 minutes [21] The inspiratory to expiratory ratio is approximately 2:1 in resting green sea turtles (calculated from [14]) and 1:1 in lightly-anesthetized, spontaneous breathing loggerhead sea turtles (calculated from [31]). The product of tidal volume and respiratory rate, minute ventilation, has ranged from 11 ml/kg/min for juvenile, swimming loggerhead sea turtles at 22 - 25 ^{0}C (measured at BTPS) [1], to 21 ml/kg/min for resting green sea turtles at 29 ^{0}C [14]. Knowledge of these respiratory measurements may provide guidelines for controlling ventilation but the anesthetist must recall that tidal volumes, breaths per minute, and minute ventilation all decrease with decreasing temperature [2]. Ultimately, a definitive evaluation of respiratory support requires blood gas measurements.
Although intraoperative blood gases and direct arterial blood pressures are generally not available, two small case reports of dorsally recumbent Kemp's Ridley [9] and loggerhead sea turtles [13] have shown that these turtles may become hypoxemic and develop a mixed acidosis. Fortunately, there were no apparent ill effects in either report. The oxygen-hemoglobin dissociation curve is different between aquatic and terrestrial turtles and the hemoglobin of aquatic species tends to have a lower oxygen affinity. This may be one of the mechanisms that permit them to withstand prolonged periods of anesthesia-induced hypoxia. In awake, diving sea turtles, similar acid-base changes (pH, carbon dioxide, lactate concentrations) do not seem to occur, despite the prolonged apnea and low oxygen tensions [21]. Thus the blood gases from these anesthetized sea turtles are contradictory to blood gases obtained during spontaneous diving in sea turtles and suggest that the physiologic changes observed during anesthesia may not be actual "dive reflexes". How to improve or prevent these pathologic changes are currently unknown.
Monitoring ventilation with a capnometer can be misleading because the end-tidal CO_2 measurements may found not to reflect the actual $PaCO_2$ concentrations. Furthermore, the Alveolar-arterial CO_2 gradient may not be consistent throughout the procedure in any given turtle [9,13]. Oxygenation should be assessed with blood gases although this is often not practical. Pulse oximetery has not been validated in aquatic turtles although has been used (see above).
Temperature - cloacal temperatures should be monitored and temperature maintained within the turtle's preferred optimal temperature zone (see above) during anesthesia and recovery. A circulating warm-water pad under the turtle, a forced warm air blanket, or an overhead heat lamp may be useful.
Fluids - fluids should be administered to all sick, debilitated, or traumatized sea turtles or those undergoing extensive surgery. Warmed fluids can be administered subcutaneously, epicoelomically, ICo, or IV(5 - 10 ml/kg/hr). A cut-down can be performed on a jugular vein if either it or a peripheral vein cannot be catheterized percutaneously. A venous catheter also can be placed intraoperatively if abdominal surgery is being performed by using the readily accessible mesenteric veins. For sea turtles, the dorsal cervical sinus can be catheterized [13].

Post-anesthetic Recovery
Although the recovery phase is typically prolonged, all turtles must be monitored and supported until fully awake. Turtles that have undergone a lengthy anesthetic procedure (greater than two hours) are likely to be hypothermic, hypoxemic, and acidemic (both hypercapnic and lactic acidosis) [9,13]. In our experience with Kemp's Ridley sea turtles, the duration of recovery did not correlate with type of carrier gas, method of ventilatory weaning, use of selected pharmacological agents (atropine or dobutamine), and did not always correlate with the duration of anesthesia [9]. With these turtles, a progressive tachycardia and a sudden onset of tachypnea characteristically preceded awakening. Within minutes of these changes, turtles were arousable and could be extubated. Thus turtles cannot be left unattended, despite the possibility of a long recovery, as delaying their extubation after sudden awakening could cause occlusion of the endotracheal tube and an airway obstruction.

Conclusions
Fortunately, the aquatic turtle is capable of enduring prolonged periods of apnea as well as possessing intermittent breathing patterns, adjustable metabolism, and an extraordinary tolerance to hypoxia. Thus although many of the anesthetic manipulations do not cause the demise of our patients, it is likely that many anesthetic successes are due to the adaptability of the turtle. Local anesthetics, injectable anesthetics, and inhaled anesthetics have all been used effectively without apparent ill effects in providing surgical anesthesia.

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