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EUTHANASIA

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Introduction

Euthanasia is the process of "ending the life of an individual animal in a way that minimizes or eliminates pain and distress" (Leary et al. 2013). Electing euthanasia can be among the most difficult decisions anyone with responsibility for an animal's welfare can face. Although not exclusively a veterinary responsibility, the principles of the veterinarian's oath come into play, in particular the "relief of animal suffering" (American Veterinary Medical Association [AVMA] 2017) when cure or rescue is not possible. As applied to marine mammals, and particularly for large cetaceans, euthanasia is also a technically challenging and potentially hazardous undertaking. Veterinarians, marine mammal biologists, stranding network responders, keepers, and curators may be faced with the decision of whether or not to euthanize a marine mammal as a humane act to end its suffering. In reaching a decision to euthanize, one must determine that the animal is suffering with negligible chance of recovery or successful rescue; that euthanasia can be carried out safely for personnel; that the necessary equipment, materials, and technical skills are available to complete euthanasia successfully; that scavengers and the environment will not be put at risk as a result; and that caretaker and public concerns have been taken into account and addressed to the fullest extent possible. This chapter reviews euthanasia methods in marine mammals, so that informed decisions on techniques can be made, after treatment, direct rescue, or rescue and rehabilitation have been ruled out as viable options. The unique challenges of cetacean euthanasia are given special attention. Also included is information on carcass disposal and avoidance of relay toxicity.

Greer et al. (2001) gave a sound examination of marine Q1 mammal euthanasia issues and methods. Since that time, however, several developments have advanced the practice of marine mammal euthanasia. The American Veterinary Medical Association Guidelines for the Euthanasia of Animals have been updated and expanded with additional information on euthanasia situations outside of the clinic or laboratory, including marine mammals in stranding or human care settings (Leary et al. 2013). US marine mammal stranding networks have been surveyed for their euthanasia practices, and subject matter experts convened at a workshop for collaborative development of recommendations for euthanasia of stranded cetaceans with results published in a technical memorandum (Barco et al. 2016). The International Whaling Commission has held two workshops involving cetacean euthanasia (IWC 2010, 2014). Fisheries and Oceans Canada has produced recommendations on cetacean euthanasia (Daoust and Ortenburger 2015).

Advances in anesthetic protocols that can be adapted for pre-euthanasia sedation and analgesia have been made across multiple taxa (see **Chapter 26**), including even at-sea sedation of right whales (*Eubalaena glacialis*) for disentanglement (Moore et al. 2010). Plus, additional works on physical (Coughran, Stiles, and Mawson 2012; Hampton et al. 2014b) and chemical (Daoust and Ortenburger 2001; Dunn 2006; Kolesnikovas et al. 2012; Harms et al. 2014) euthanasia of cetaceans have been published.

General Considerations

Human safety must be the top priority in any marine mammal euthanasia situation (Barco et al. 2016). It is easy to get caught up in the event and overlook safety concerns. Having a designated safety officer overlooking the entire team and scene is advisable, as is first aid, CPR, or more advanced emergency medical training within the team. Potential hazards include bites, drowning, blunt or crushing trauma from flukes or pectoral fins, foot or leg entrapment under a large animal, zoonotic disease, drug exposure (e.g., ultrapotent opioids), sticks from needles (particularly from needles attached to pressurized loaded syringes and larger bore than those typically used), ballistics or explosives (see physical methods of euthanasia, below), exhaustion, hyperthermia, and hypothermia. Working close to a live cetacean in the surf is not recommended, especially in water greater than knee deep, in part because of the tendency for a deeper trough to form around and under the animal and the potential for it to roll and cause entrapment. The least hazardous time to work close to a stranded cetacean is at low tide during daylight hours, which can impose a narrow window of time for safe access, and is an important operational constraint for all parties to recognize. Flukes of a large cetacean are a particular danger for injury or death. Use of personal protective equipment (PPE; e.g., gloves, wet suits, close-toed footwear) and a means to clean and disinfect hands (e.g., hand wipes, hand sanitizer) are recommended. Using Luer lock rather than Luer taper syringes reduces the chance of drug exposure from spray if a needle detaches or a hub breaks while under pressure during injection.

The basis for considering euthanasia of any animal arises when its welfare is so negatively affected that death is assessed as preferable to continued existence. Animal welfare has been described as having three components: the animal functions well, feels well, and can perform innate behaviors and species-specific adaptations (Leary et al. 2013). If these three components of welfare are missing and cannot be restored by treatment, rescue, or rehabilitation, then euthanasia is an appropriate option. Rescue and euthanasia are not the only options, however. Nature has taken its course for eons (before humans ever intervened) in a positive manner for marine mammals in distress, and allowing them to expire naturally can be reasonably argued. It may be the only reasonable alternative if intervention cannot be performed safely or effectively. Because a stranded animal may survive and suffer for days before succumbing, however (Daoust and Ortenburger 2001; Kolesnikovas et al. 2012; Harms et al. 2014), humane impulses typically motivate efforts to end the animal's suffering. The suffering can result from endogenous factors, such as system and organ breakdown, in addition to exogenous factors, such as bird damage to eyes, orifices, and epidermal and dermal tissues.

Because of constraints on situational control when dealing with wildlife, including in some marine mammal stranding circumstances, it is recognized that the quickest and most humane actions may not meet all criteria for euthanasia but may be preferable to the alternatives (i.e., humane killing; Leary et al. 2013). Minimizing pain and suffering to the greatest extent possible by the best available means must be the priority in all cases, however.

Avoid ill-advised rescue attempts that increase distress and pain without altering the outcome. This is a major challenge, especially when simply returning the animal to the water is sometimes mistakenly perceived as a success. While some strandings are truly accidental (e.g., large tidal flux in a feeding area, bottom conditions that confuse echolocation, etc.), or involve a mix of healthy and unhealthy animals in a mass stranding, most single cetacean strandings involve some form of serious injury or illness. These conditions will not be resolved by refloating the animal and may simply result in the animal restranding elsewhere or dying unobserved at sea. Conversely, some pinnipeds just need a place to haul out and rest undisturbed before returning to the water of their own volition. Putative rescue methods that can inflict permanent debilitating and ultimately fatal injuries, such as attempting to haul large whales by the flukes, should especially be avoided. Although no comprehensive review of large whale rescue assessments and outcomes exist, to our knowledge, there are anecdotal reports of whales rolling into trenches being dug for their attempted rescue and having the blowhole submerged, suffocating when weight is concentrated on the sternum during trench digging, and swimming away entangled in rescue line once freed from a shoal (see Moore [2014], for discussion of severe welfare impacts of entanglement).

Hospice

Whether or not a stranded marine mammal will ultimately be rescued, euthanized, or die on its own, basic supportive care should be instituted as soon as safely practical. The goals of such measures prior to rescue are to avoid further injury and minimize physiologic deterioration that would eventually make death inevitable, even if the animal were freed from its stranding situation, while the goals prior to death are to keep the animal as comfortable as possible and ease its passing. The latter qualifies as a form of basic hospice care, a concept that has emerged recently in zoological medicine settings (Jessup and Scott 2011). Components of supportive or hospice care for a stranded marine mammal include the following: ensuring that breathing is unimpeded by water, sand, and debris; protecting from scavengers; making appropriate postural changes if possible (upright in sternal recumbency, fins and flukes in anatomically neutral positions); providing shade or other sun protection (e.g., tarp, canopy, wet towels or sheets, or zinc oxide); assisting temperature regulation; and minimizing handling and disturbance (2005). Scavengers do not wait for a defenseless stranded animal to expire before taking advantage of a fresh source of food, and can inflict extensive damage to skin and eyes. Abnormal forces on malpositioned pectoral fins or flukes could cause joint pain to the point of dislocation. Excessive sun exposure can cause blistering equivalent to second-degree burns over all exposed body surfaces, with associated pain and fluid loss as blisters rupture. Hyperthermia is more commonly a problem than hypothermia for a marine mammal removed from the aquatic environment, where thermoregulatory mechanisms function best, but either can occur, depending on species, body condition, and ambient conditions. Hyperthermia can be prevented by providing shade or by dousing with water, especially the flukes and fins.

Medications for relieving anxiety and pain as a component of hospice may be more readily applied for animals under human care in managed environments than in stranding circumstances. In particular, for larger marine mammals though, the effective drug quantities and duration of treatments required while an animal expires naturally over the course of days can both rapidly deplete inventory and compromise the ability to euthanize the animal later, and/or cope with additional stranded animals that may appear concurrently or shortly thereafter. In some situations, when an animal is severely debilitated and already close to death, sedatives and analgesics may suffice, without the need to institute other physical or chemical euthanasia methods.

Stranded Animals

A cetacean or manatee (*Trichechus* sp.) is considered stranded when it is found dead or live on land, is found in shallow water or otherwise out of normal habitat and unable to return to deeper water or normal habitat, or is in need of medical attention. Other marine mammals that normally spend periods of their lives on land, such as pinnipeds, sea otters (*Enhydra lutris*), and polar bears (*Ursus maritimus*), are considered stranded when found dead or live, hauled out onshore, and unable to return to the water, or in need of medical attention (see **Chapter 1**). Many marine mammals are considered protected species around the world. When a stranded marine mammal is found alive, the responsible government agency (e.g., National Marine Fisheries Service for US cetaceans and pinnipeds; US Fish and Wildlife Service for US manatees, sea otters, and polar bears; Department of Conservation in New Zealand; Department of Environment and Conservation in Western Australia) or authorized stranding network personnel must be notified. The complex decision of whether the animal should be rehabilitated or euthanized rests with the governing agency and its designated representatives, its stranding network personnel.

All stranded marine mammals must be given a physical examination to guide the initial assessment. Examination findings that may indicate euthanasia include the following: serious disabling locomotor injuries such as vertebral fractures or dislocations (**Figure 28.1**); wounds that involve a large percentage of surface area or that have full penetration into the thoracic or abdominal body cavity; blistering and scavenger damage to a large percentage of surface area (**Figure 28.2**) or critical areas such as eyes and blowhole; significant hemorrhage from the anus, genital opening, blowhole, or mouth; loss of reflexes at the anus, genital opening, blowhole, tongue, eyelids, or eyes; other signs of neurological abnormalities; marked prolonged hypothermia or hyperthermia with core body temperatures <95°F or >104°F (<35°C or >40°C), respectively; and extended length of time beached (over 12–48 hours, depending on degree of decompensation and further injury in the course of stranding; Needham 1993; Geraci and Lounsbury 2005).

The longer a purely aquatic marine mammal remains stranded, the poorer its chances for survival, even if it was otherwise healthy at the time of stranding. Besides the potential of sustaining physical injury from surf, substrate, sunburn, and scavengers, physiological deterioration proceeds rapidly through several interrelated stress and shock pathways (Geraci and Lounsbury 2005) in a time-, size- and exposure-dependent manner. Thermoregulation is compromised out of water, commonly leading to hyperthermia. Dehydration contributes to hypovolemia and electrolyte imbalances. Outside of the buoyant support of water, gravitational forces exert inexorable forces on the heart and lungs, leading to cardiopulmonary insufficiency and collapse. Major portions of the lungs of

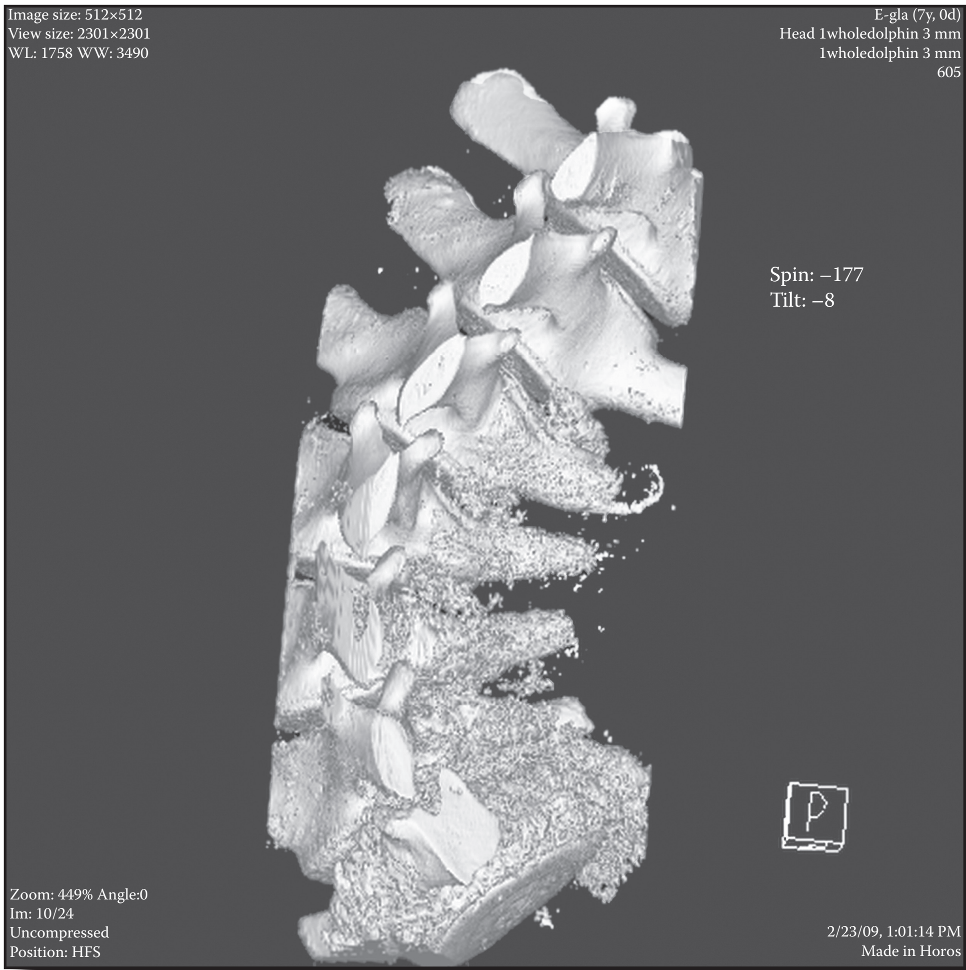

Figure 28.1 3-D volume rendering of CT scan of caudal spine from a stranded, euthanized 2-year-old right whale, illustrating scoliosis and dystrophic mineralization (case #1, Harms et al. 2014). This whale had been previously observed with an entanglement of the flukes and peduncle, shed prior to stranding but with scars remaining. Vertebral instability resulting from the entanglement is thought to have led to the deformity and degenerative changes, compromising locomotion and likely inciting pain with every fluke stroke. (CT scan by D. R. Ketten and S. Dennison, Woods Hole Oceanographic Institution, Computerized Scanning and Imaging Facility, copyright D. R. Ketten, used with permission; 3-D volume rendering in Horus by C. A. Harms.)

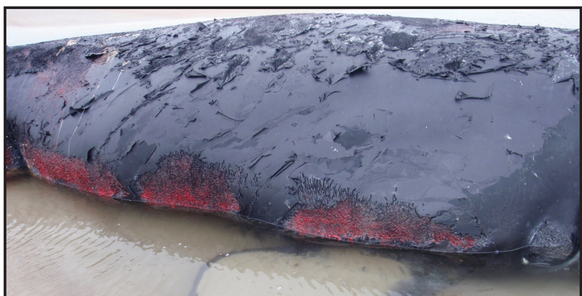

Figure 28.2 Ruptured blisters and skin peeling from sun exposure, and scavenger damage from gulls and crabs, in a live-stranded right whale (case #1, Harms et al. 2014). This represents the functional equivalent of second-degree burns over approximately 80% of the exposed body surface.

live-stranded large whales become consolidated or atelectatic, with no gas exchange except in the upper regions. The sheer effort of lifting the thorax to breathe can exhaust a large cetacean. Catecholamine (e.g., epinephrine) and glucocorticoid (e.g., cortisol) release into circulation in response to stranding contributes to electrolyte abnormalities, myocardial damage, and shock, with reduced perfusion of peripheral tissues and major organs. Rhabdomyolysis from exertion attempting to escape the stranding situation, weight on dependent muscle masses, and trauma from surf result in myoglobinemia, which can contribute to renal failure and hyperkalemia, which can add to cardiac irregularities and arrest. The larger the animal and the less buoyant support it has through the tidal cycle, the more rapidly it will decompensate, with evidence of shock appearing in as little as a few hours. Although a stranded animal may reach the point of nonrecovery in 12–36 hours, it may still take several days to die on its own. Self-rescue can occur on the next high tide after the initial stranding, or on the second high tide, if the tides are markedly bimodal. For a large whale, self-rescue may represent the animal's best chance, considering the time necessary to mount an appropriate response. It is also well worth affording the animal the opportunity for self-rescue if there is any question about its condition, and particularly if immediate rescue is not feasible. Beyond three or four high tides after stranding, odds for either successful assisted rescue or self-rescue diminish rapidly.

The stranding location and logistics of humanely and safely transporting the animal to a rehabilitation center or back into deep water may also factor into a euthanasia decision. These constraints can yield unsatisfying, but unavoidable, results when dealing with an animal that might otherwise have been rescued, were it not for such factors as severe weather, rough seas, or lack of vehicle or heavy equipment access.

A thorough record of the animal's condition before euthanasia is essential adjunct information to necropsy reports. Each stranding must be considered as a unique event, and complete biological, medical, and environmental data should be obtained. Because many strandings are of public and media interest, thorough and careful communication of the animal's condition and reason for euthanasia should be made to the stranding volunteers and public as soon as solid information is available. Close emotional identification with a stranded marine mammal can occur rapidly, and these emotional ties deepen with close proximity and with time. Some stranding response organizations prefer to remove an animal from the beach and from public view prior to euthanasia. Visual barriers have been recommended when euthanasia is carried out on site (Geraci and Lounsbury 2005). While these practices may well have merit in some cases to spare the public from emotionally disturbing sights, in an era of ubiquitous smartphone photographs and videos, and where drones can readily be deployed for live-streaming from many angles, any action perceived as a cover-up may well be more negatively received than a well-explained humane procedure, despite the undeniably difficult sight of an animal's demise.

Animals under Human Care

Marine mammals kept in managed environments, such as zoos and aquariums, often have greater access to veterinary care during their lifetimes. Because these animals are usually intensively managed, an intimate relationship often develops between the animal and its caregivers, visitors to the facility, and virtual visitors through social media. The decision to euthanize a charismatic marine mammal, particularly one in a display facility, is subject to public scrutiny. It is recommended that an open and positive relationship be established with everyone involved, including the media in multiple formats, at the onset of an illness. Thorough communication from the veterinarian explaining the extent of an illness, the differential diagnosis, and the perceived quality of life for the animal is usually well received, regardless of views on maintaining particular marine mammal species in managed environments. Such efforts should help preserve positive feelings and minimize the development of negative feelings that might arise when a popular animal is euthanized.

Methods of Euthanasia

There are three basic mechanisms by which euthanasia methods cause death: (1) depression of neurons vital for life (e.g., typically by overdose with chemical anesthetics); (2) hypoxia, by either direct physical means (e.g., decapitation [not applicable to marine mammals]) or indirect means (e.g., paralytics); and (3) physical disruption of brain activity and destruction of neurons vital for life (e.g., captive bolt, ballistics, implosion; Leary et al. 2013). Euthanasia methods should result in loss of consciousness prior to loss of muscle movement, cardiac or respiratory arrest, and/or brain function. There are many methods applicable to accomplish these ends in various species. Marine mammals present unique circumstances, however, and techniques effective and appropriate in one circumstance may not be so in another. The available methods can be broadly classified as chemical (inhalant or injectable agents) or physical means, the relative advantages and disadvantages of which are considered in greater detail below.

Although many methods will accomplish death, only a few are considered acceptable by published guidelines (Close, Banister, and Baumans 1996; Leary et al. 2013). In the 2013 AVMA Guidelines for the Euthanasia of Animals (Leary et al. 2013), a panel of experts evaluated and updated methods of euthanasia to determine humaneness and acceptability. The panel used the following criteria:

1. Ability to induce loss of consciousness and death with a minimum of pain and distress
2. Time required to induce unconsciousness
3. Reliability
4. Safety of personnel
5. Irreversibility
6. Compatibility with intended animal use and purpose
7. Documented emotional effect on observers or operators (minimizing such effects)
8. Compatibility with subsequent evaluation, examination, or use of tissue
9. Drug availability and human abuse potential
10. Compatibility with species, age, and health status
11. Ability to maintain equipment in proper working order
12. Safety for predators or scavengers should the animal's remains be consumed
13. Legal requirements
14. Environmental impacts of the method or disposition of the animal's remains

Although earlier editions of the guidelines were developed primarily with domestic animals in mind, the recent edition has expanded sections on nondomestic species and free-ranging situations. All of these criteria should be considered when electing euthanasia of a marine mammal. The guidelines recognize that in some free-ranging wildlife situations, including marine mammals, it may not be possible to meet all criteria, with the most humane option regressing to humane killing versus euthanasia. Humane killing is defined as "killing performed in a manner that minimizes animal distress, but may not meet the requirements of euthanasia due to situational constraints" (Leary et al. 2013). This recognition does not condone a lower standard, however. Minimizing pain and distress to the greatest extent possible by the best means available under the circumstances at hand must be the goal in all cases.

A humane death is described as one that minimizes pain, distress, and anxiety prior to loss of consciousness, and results in rapid unconsciousness followed by cardiac or respiratory arrest (Leary et al. 2013). Methods that do not create unconsciousness first (e.g., paralytics, KCl, $MgCl_2$, hypothermia, cyanide, strychnine) are not considered humane to use alone for euthanasia in a conscious animal. Acceptable methods, as classified by the AVMA panel, are those that can be used alone in a conscious animal. However, if an animal is properly sedated to a level of unconsciousness, any method of euthanasia is considered humane (i.e., acceptable with conditions). Based on the following discussion of the various methods available for euthanasia, the veterinarian, animal care personnel, and stranding responder can make informed decisions on the most appropriate methods to euthanize an animal in various situations.

Chemical Methods

Injectable Agents Injectable agents are considered among the most rapid, reliable, and desirable means of euthanasia available (Leary et al. 2013). They have the added advantage of social acceptability by virtue of familiarity with euthanasia procedures that many people have experienced with their pets. Even when pre-euthanasia sedation and analgesia steps are required prior to administering a euthanasia drug, which slows the process somewhat, each additional step incrementally reduces pain and suffering. Potential disadvantages as applied to marine mammal euthanasia situations occasionally may include a need for physical or chemical restraint prior to administration, use of large volumes and expense for large animals, difficult vascular access, an excitement phase that could be distressing to observe or potentially dangerous to be near, and need for specialized delivery systems (e.g., large and long needles for large cetaceans). General social acceptability of injectable euthanasia techniques versus physical methods notwithstanding, the size-appropriate equipment required and its application for large animals may still be disturbing to onlookers, and prior explanation of the process and equipment is highly advisable.

Compared with species more commonly encountered in veterinary medicine, drug effects and reactions are not as well studied in marine mammals. Variations among species, individuals, physiological status, and setting all have the potential to yield unpredictable reactions (see Pre-euthanasia Sedation and Analgesia below for specific examples), even for drugs that have previously been successfully employed. In the event of a violent response, if the animal cannot be effectively restrained, it is safer to back away and let the animal expend itself.

A reasonably accurate measurement or estimate of body weight is essential for appropriate dosing (Barco et al. 2016). An accurate body weight is also valuable for managing logistics for any attempted rescue, or for carcass moving and disposal. Despite the commonly held maxim that euthanasia solution cannot be overdosed (because the intended result is achieved with either accurate dosing or overdosing), there are distinct disadvantages to overdosing euthanasia drugs. These include increased cost (particularly with large animals or mass stranding events), loss of inventory that may be needed on short notice before the ability to resupply (again, more of a concern for massive events), gross pathologic and histopathologic changes that may cloud interpretation of postmortem findings (e.g., vascular pooling, congestion, organ enlargement), and hazards of relay toxicity to scavengers, or environmental contamination, if proper disposal of the carcass following euthanasia is not possible. Conversely, the drawbacks of underdosing euthanasia solution are more readily apparent, most importantly prolonging suffering of the animal but also a greater likelihood of inducing an excitement phase and reducing safety of personnel working close to the animal. Platform scales may be used to weigh both small and large animals in captive settings, particularly if weighing is a trained medical behavior. In stranding situations, smaller animals can be weighed directly using slings and load cell scales. For larger animals, or when direct weighing is otherwise not feasible, weight can be estimated from length-to-weight equations and graphs. These have been generated for several smaller cetacean species that commonly strand in the southeastern United States (**Figure 28.3**; Barco et al. 2016), and additional sources are available for large cetaceans (Lockyer 1976; Fortune et al. 2012).

From calculated values, adjustments to the working weight can be made up or down, based on body condition assessment and examination of scatter plots depicting known variation in body weights by length (Barco et al. 2016). Doses can be further adjusted based on clinical assessment of the animal's health status. Because of differences in body conformation, weights of different species can vary dramatically for individuals of the same length. Furthermore, comparatively small differences in length may lead to a profound difference in weight. For example, using published large whale equations (Lockyer 1976), the estimated weight of a 10 m humpback (*Megaptera novaeangliae*) calculates to 14,700 kg, compared with a 10 m fin whale (*Balaenoptera physalus*) at 6,400 kg, or a 9 m humpback at 10,800 kg. Visual estimates of length can be wildly inaccurate and are almost invariably low; therefore, a tape measure stretched out parallel to the animal is strongly recommended, exercising due caution in proximity to the flukes. Girth (or width as a surrogate) has

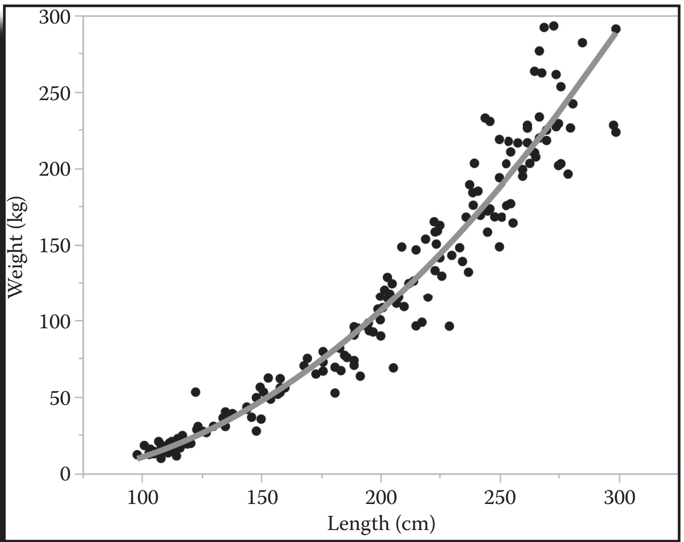

Figure 28.3 Example of a length-to-weight graph that can be used to estimate weights of stranded cetaceans in the field when weighing is not feasible. Data are from 171 bottlenose dolphins stranded in North Carolina and Virginia. $W = (0.004468 \times [L - 196833]^2) + (1.3728948 \times L) - 168.61$, where W is weight in kg and L is length in cm. $N = 171$, $R^2 = 0.939$. (Adapted from Barco, S. G. et al., Collaborative development of recommendations for euthanasia of stranded cetaceans, in *NOAA Technical Memorandum NMFS-OPR-56*, 83, Silver Spring, MD: US Department of Commerce, NOAA, 2016.)

similarly marked effects on weight (Barratclough et al. 2014), although it is somewhat more difficult to measure and apply to weight calculations.

Routes of Administration Intravascular administration of an acceptable pharmaceutical agent is considered the most rapid and reliable means of obtaining humane euthanasia in mammals (Close, Banister and Baumans 1996; Leary et al. 2013) and is the common method used in marine mammals. Peripheral veins can be found in anatomical grooves of cetaceans. The vessels lie under the dermis and can be accessed with superficial techniques, particularly in the fluke. When the vasculature starts to collapse in dying cetaceans, the ventral peduncle may be the most useful site for injection. For small cetaceans a 2.5 cm, 20-gauge needle is suitable; for larger cetaceans, use a 3.8 cm needle; and for larger whales, a needle of 5.1 cm or longer is needed (Sweeney 1989). To access deeper vessels, a 15 cm needle can be used for an orca-sized whale, and a 30–46 cm needle for a larger whale (Royal Society for the Prevention of Cruelty to Animals [RSPCA] 1997). Sites for venipuncture in different marine mammal groups are described elsewhere (see **Chapters 37 through 45**).

Disadvantages of the intravenous (IV) route are the difficulty in locating peripheral vasculature in debilitated or traumatized animals or animals in various stages of shock, the potential danger to humans in restraining animals for access to vessels, and the extreme danger of working around the flukes of a large cetacean. Additionally, considerable drug dilution and time to travel from peripheral vessels means that larger doses are required and onset of action is slower than if administered centrally.

Intracardiac injections are painful and are unacceptable in a conscious animal but acceptable in anesthetized, moribund, or unconscious animals (Close, Banister, and Baumans 1997; Leary et al. 2013). Using centrally administered routes allows more rapid onset of action, the ability to accommodate large volumes more quickly, smaller drug volume requirements, reliable access to the circulatory space, and the ability to work in a relatively safe environment, away from the flukes. Thus, for euthanasia of cetaceans, following nonresponsiveness induced with intramuscular dosing with sedatives and analgesics, intracardiac injections can be used (Harms et al. 2014; Barco et al. 2016). Intracardiac access in large animals requires custom-made long and robust needles (**Figure 28.4**; Geraci and Lounsbury 2005; Harms et al. 2014). Large volumes as required for large whales can be administered from an inexpensive pressurized plastic canister adapted for the purpose (**Figure 28.5**).

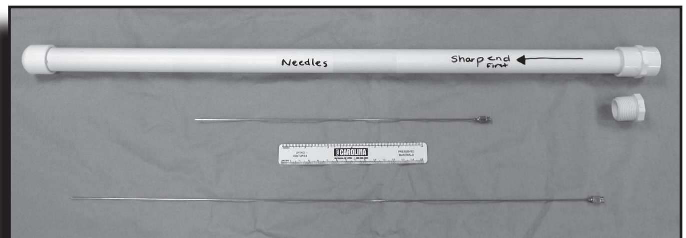

Figure 28.4 Custom-made, 31 cm 16-gauge and 55 cm 18-gauge needles used for deep intramuscular injections in large whales, with polyvinyl chloride tube carrying case. Ruler = 15 cm.

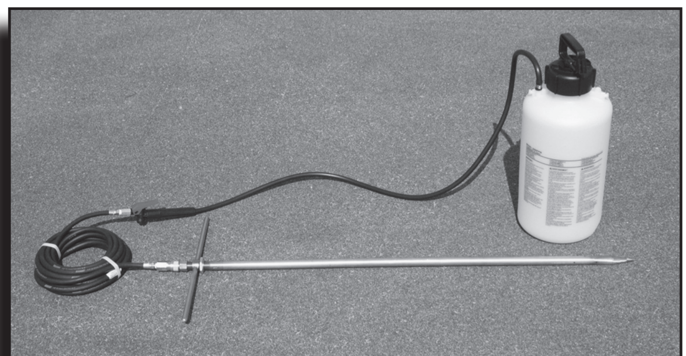

Figure 28.5 Robust customized intracardiac needle and drug delivery system. The needle is 1 m long, 21 mm in outer diameter, 12 mm in inner diameter, with a threaded point inserted at one end for ease of cleaning and safe transport and handling, six 3 mm side ports to avoid tissue coring, heavy gauge to reduce bending, a threaded crossbar handle to facilitate insertion, and a quick disconnect coupling to the tubing. The pressurized canister is a commercially available sprayer. (Reprinted with permission from Harms, C. A. et al., Low-residue euthanasia of stranded mysticetes, *J Wildl Dis* 50: 63–73, 2014.)

The best access points for intracardiac injections are low on the body wall via right or left axillary spaces, or ventrally from a parasternal approach (Barco et al. 2016). For large animals that cannot be rolled, this requires waiting until low tide to carry out this procedure.

If an injection cannot be administered IV, then less preferred routes can be used. Intraperitoneal administration is considered acceptable by AVMA guidelines (Leary et al. 2013). However, some drugs may irritate peritoneal tissues and are slow to absorb, and thus unpredictable, leading to prolonged onset of action and variation in the effective dose (Leary et al. 2013). The thickness of the skin, blubber, and muscle must be taken into account when selecting needle length for intraperitoneal injection, and access may be difficult in large whales. Intraperitoneal injection may be more appropriate for smaller animals; however, the human risks associated with restraint for injection remain. Intrahepatic administration of euthanasia solutions has been considered acceptable in cats (Grier and Schaffer 1990; Leary et al. 2013) and has been used with some success in small cetaceans (Barco et al. 2016). When compared with the intraperitoneal route, intrahepatic administration of sodium pentobarbital in cats resulted in minimal response to injection, moderate accuracy, low rate of excitability, and a significantly faster response, followed by cardiac standstill (Grier and Schaffer 1990). Both intraperitoneal and intrahepatic administration may be less acceptable to the public or volunteers than intravenous dosing.

The intramuscular (IM) route may used for euthanasia with ultrapotent opioids (e.g., etorphine, carfentanil; see below), or for pre-euthanasia sedative and analgesic drugs in two-step or multiple-step euthanasia procedures. As with intraperitoneal and intrahepatic injections, intramuscular injections require sufficiently long needles to pass through the thick skin, fat, and blubber layers of large marine mammals. Custom-made 31 cm 16-gauge and 55 cm 18-gauge needles have been used successfully for mysticetes (Harms et al. 2014; **Figure 28.4**). Though long, the small diameter elicits minimal response to insertion, with successively less response as multiple doses are administered. Large volumes may be required; therefore, limit volumes to ~30 ml per IM injection site even in massive animals, and distribute among multiple sites, to ensure adequate systemic absorption. Injection site distribution can be achieved using long needles to deposit the drug in deep, middle, and shallow intramuscular sites during a single needle excursion; by multiple needle insertions; or by using needles with multiple side ports. Moore et al. (2010) note that a needle with three equidistant side ports near the needle tip can deliver three independent boluses from a single needle, maximizing uptake.

The intranasal or blowhole route has been used successfully to deliver pentobarbital (60 ml, 390 mg/ml) to a 13.5 m standard-length fin whale (*Balaenoptera physalus*), resulting in sufficient sedation to allow safe use of a fluke vessel for final euthanasia (Dunn 2006). Drugs successfully delivered via the intranasal route in other species (e.g., midazolam, morphine, xylazine) have potential pre-euthanasia application in marine mammals (Barco et al. 2016).

Subcutaneous administration has an unacceptably long absorption of drug and onset of action. Intrathoracic, intrapulmonary, intrarenal, intrasplenic, and intrathecal routes irritate tissues and are only considered conditionally acceptable for administering euthanasia agents in anesthetized or moribund animals (Close, Banister, and Baumans 1996; Leary et al. 2013); these routes have little advantage over other routes of administration in marine mammals. Retrobulbar injections have been attempted in large cetaceans, using custom-made long needles, in an attempt to access a venous plexus from a position of relative safety far from the flukes, but abundant retrobulbar fat deposits may limit efficacy of this route of administration (Harms et al. 2014; Barco et al. 2016).

Pre-euthanasia Sedation and Analgesia

Handlers may risk serious personal injury when working in close proximity to large marine mammals during administration of any injection, especially in uncontrollable environments (such as on ice floes with polar bears, or in water of any depth with adult pinnipeds or large whales). Sedating the animal prior to euthanasia decreases but does not eliminate the risk to personnel during handling. Deep sedation and analgesia is also required for two-step euthanasia procedures that would otherwise not be considered acceptable, such as those using intracardiac injections, KCl, or exsanguination. Sedation would also be beneficial while setting up for an acceptable physical euthanasia technique (see below). In animals that are already in poor health or severely compromised by the effects of stranding, pre-euthanasia sedative–analgesic drugs may effect euthanasia themselves.

Sedation can be accomplished utilizing remote darting systems or IM injections (Barco et al. 2016; see **Chapter 26**). Pre-euthanasia drugs that have been used in cetaceans include midazolam, diazepam, acepromazine, xylazine, and other alpha-2 agonists, meperidine, butorphanol, and others (Barco et al. 2016). Of these, the alpha-2 agonists and opioids (e.g., meperidine, butorphanol) provide analgesia essential for 2-step protocols including intracardiac injections. Benzodiazepines (midazolam and diazepam) and acepromazine provide beneficial anxiolysis and sedation, albeit without analgesic properties; they can potentiate the sedative and anesthetic effects of other drugs and can reduce potential excitatory side effects. Midazolam and the opioid drugs are listed as controlled substances by the US Drug Enforcement Agency (DEA), which can limit their accessibility to some stranding response organizations, while acepromazine and xylazine are not so listed. Because of their use in large animal medicine, acepromazine and xylazine have the additional advantages of being available in quantities suitable for use in large marine mammals, and at reasonable cost (Harms et al. 2014). Compounded concentrated midazolam (50 mg/ml) and butorphanol (50 mg/ml) have been delivered by dart at sea for sedation and successful disentanglement of right whales, at approximate doses of 0.1 mg/kg for each drug (Moore et al. 2010). If available, these concentrated formulations could also be used for pre-euthanasia sedation and analgesia, although they are expensive, and extra care in handling needs to be employed.

Adverse reactions have been noted in some species in response to some sedatives and analgesics. Risso's dolphins (*Grampus griseus*) have exhibited excitation following IM injections with alpha-2 agonists, including xylazine and medetomidine (Barco et al. 2016). Excitation has also been observed in a gray whale (*Eschrichtius robustus*) following xylazine injection (Gulland pers. comm.). Alpha-2 agonists are therefore not recommended as the initial or sole premedication in Risso's dolphins or mysticetes. Treatment with midazolam and/or acepromazine prior to xylazine has resulted in smooth induction in these species, while retaining the beneficial analgesic effects of xylazine, without the visually distressing and potentially dangerous side effects (Harms et al. 2014; Barco et al. 2016). Acepromazine has been associated with violent reactions in common dolphins (*Delphinus delphis*; Barco et al. 2016). Common dolphins are considered particularly sensitive to handling and noises, and a quiet hands-off approach to the extent possible is recommended with this species regardless of drugs used (Barco et al. 2016). False killer whales (*Pseudorca crassidens*; Atkins, Boyd, Ewing, Lovewell, Walsh pers. comm.) and a white-beaked dolphin (*Lagenorhynchus albirostris*; Harms pers. obs.) have exhibited violent agonal responses following midazolam, acepromazine, and xylazine. In the case of the false killer whale mass stranding, similar agonal responses were observed in one whale without any drug administration and may therefore have reflected their underlying physiologic status at the time of death; previous use of midazolam alone in false killer whales housed in facilities has not been associated with agitation (Walsh pers. comm.). Additionally, the white-beaked dolphin had a functional pheochromocytoma and may have been sensitized with endogenous catecholamines.

Some pre-euthanasia sedative–analgesia protocols (Barco et al. 2016) that have been effective in previous cetacean euthanasia cases based on a survey of US stranding organizations include the following: (1) meperidine 4 mg/kg IM; (2) midazolam 0.05–0.1 mg/kg IM, acepromazine 0.2–1 mg/kg IM, xylazine 3–4 mg/kg IV or IM, with 5–10 minutes between drugs, and repeated if necessary; and (3) acepromazine 1 mg/kg IM, xylazine 2 mg/kg IM, with 5–10 minutes between doses, and repeated as necessary. The reader is referred to Barco et al. (2016) and **Chapter 26**, for additional options and details.

A local anesthetic block (lidocaine, carbocaine, etc.) in the skin, blubber, and muscle layer at the site of intracardiac needle insertion (Harms et al. 2014) may not be strictly necessary in an animal rendered nonresponsive by systemic sedatives and analgesics, but it is easily and inexpensively performed, can add an extra layer of analgesia during multiple-step euthanasia procedures, and is recommended.

Euthanasia Drugs

Barbiturates

Barbiturates are the most widely accepted mammalian euthanasia agents because of their rapid and targeted action (Close, Banister, and Baumans 1997; Leary et al. 2013). These drugs act by depressing the medullary respiratory and vasomotor centers, resulting in unconsciousness and respiratory and cardiac arrest. The onset of these reactions is quick, thus minimizing the discomfort to the animal. They are acceptable for single-agent euthanasia, unless administered via the intracardiac route, in which case pre-euthanasia analgesia should be administered. Some countries limit use of these drugs to appropriately licensed individuals (e.g., US DEA registration), thereby limiting availability in some stranding situations. Pentobarbital is the barbiturate most widely used for euthanasia. Euthanasia products containing only pentobarbital are listed as controlled DEA Schedule II drugs, while products combining pentobarbital with other agents such as phenytoin are Schedule III drugs, which are slightly less restrictive to obtain, store, and document (Leary et al. 2013).

The dosage for pentobarbital-induced euthanasia for most species is 60–120 mg/kg IV (Plumb 2015). A dose of 80 mg/kg IV has been recommended for cetaceans (Barco et al. 2016). Median pentobarbital euthanasia doses used successfully for cetacean euthanasia in the United States were 100 mg/kg IV with alpha-2 agonist premedication and 133 mg/kg IV without premedication (Barco et al. 2016). Immature gray whales 4–6 m in length have been successfully euthanized with 180–230 ml of pentobarbital solution (390 mg/ml concentration) IV (Haulena and Gulland pers. comm.). Pilot whales (*Globicephala spp.*) 4–6 m in length were successfully euthanized with 120 ml of pentobarbital solution (390 mg/ml concentration) IV (Rowell 1985). A dose of 10 mg/kg effectively induces deep anesthesia in cetaceans. This dose can induce apnea for a period potentially long enough to cause hypoxia without the animal regaining consciousness (Sweeney 1989) and would be considered humane euthanasia in circumstances where larger volumes cannot be administered. The volume of pentobarbital can be reduced by premedication with acepromazine at 100 mg/m of body length (Needham 1993) or midazolam at 15 mg/m of body length (Greer and Rowles 2000; Gulland pers. comm.), or a premedication administered on the basis of mg/kg weight estimated from length, as indicated above and in Barco et al. (2016).

Intraperitoneal administration of barbiturates is acceptable if IV or intracardiac access is not feasible (Leary et al. 2013), but may require a dose approximately 50% higher than if vascular delivery is achieved (Barco et al. 2016). Many barbiturates other than pentobarbital have an acidic pH and therefore are irritating if injected intraperitoneally.

Despite being the preferred method of chemical euthanasia in controlled settings, pentobarbital poses a risk for relay toxicity to scavengers and is environmentally persistent (Peschka, Eubeler, and Knepper 2006; Bischoff, Jaeger, and Ebel 2011; Leary et al. 2013). Pentobarbital-containing euthanasia solution is therefore not a responsible option if proper disposal of the resulting carcass is not possible or is in doubt, as is often the case in stranding situations with difficult access (Harms et al. 2014).

Ultrapotent Opioids: Etorphine and Carfentanil

Etorphine and carfentanil have been used as IM alternatives to intravenous euthanasia in some large mammals (Leary et al. 2013). They are ultrapotent opioids up to 10,000 times more potent than morphine sulfate (Leary et al. 2013). Etorphine (variously available, when available, in 1 mg/ml, 4.9 mg/ml, 9.8 mg/ml, or 10 mg/ml concentrations) and an etorphine combination with acepromazine (Immobilon L.A., etorphine 2.45 mg/ml and acepromazine 10 mg/ml) have been used for cetacean euthanasia (IWC 2014). Carfentanil has not been reported as a cetacean euthanasia agent but would likely be effective (IWC 2014). Advantages include the relatively small volumes required for effect even in a large whale, rapid onset of action, and not requiring vascular access for administration. Disadvantages include uneven commercial availability, strict regulatory oversight in most countries, cost, the potential for relay toxicity to scavengers, and the notable hazard to personnel, especially if working in a challenging stranding environment. Ultrapotent opioids are therefore generally not recommended for euthanasia of marine mammals (IWC 2014; Barco et al. 2016), but they are options to consider based on their prior effective use for that purpose.

Etorphine and carfentanil are DEA Schedule II drugs but require special DEA approval in addition to a standard DEA license to acquire. Etorphine has previously been a preferred euthanasia drug for both small and large cetaceans in the United Kingdom (RSPCA 1997, 1998) but has been less recently used, due to inconsistent availability, personnel risks, and adverse responses, including in northern bottlenose whales (*Hyperoodon ampullatus*) with reported apparent convulsions and spontaneous revival after prolonged apnea (IWC 2014). The potency of etorphine and carfentanil poses risks to personnel handling the drug, especially in the large doses needed for euthanasia (Morkel 1993), and even more so if combined with the physical hazards inherent in working close to a large marine mammal, even if it is in shallow water. Ultrapotent opioids can be absorbed through broken skin and mucous membranes (mouth, eyes, and nose). They should never be used unless a second person trained in handling opioid accidents and emergencies is on hand and a first-aid kit is present. Following euthanasia with etorphine or carfentanil, the carcass must be properly disposed of to prevent any risk of relay toxicity.

The dose of Immobilon L.A. used for euthanasia is approximately 0.5 ml/1.5 m in dolphins and 4 ml/1.5 m in whales (Greenwood and Taylor 1980; RSPCA 1997, 1998; Barnett, Jepson, and Patterson 1999). The dose of etorphine for immobilization of a variety of terrestrial mammals can range from 0.5 to 20 μg/kg, but euthanasia dosages for most marine mammals have not been determined. Using the 4 ml/1.5 m Immobilon L.A. dose above, for example, a 9 m humpback whale weighing 10,000 kg would be dosed with 16 ml, containing 39.2 mg etorphine, or 4 μg/kg.

T-61

T-61 is a mixture of a local anesthetic, a hypnotic agent, and curariform drug—tetracaine HCl (5 mg/ml), embutramide (200 mg/ml), and mebezonium iodide (50 mg/ml), respectively, in aqueous solution with dimethylformamide. This drug should only be administered IV because differential absorption may occur when administered by any other route. There has been concern that the curariform component may take effect before the onset of unconsciousness, causing distress to the animal. In dogs and rabbits, a loss of consciousness occurs simultaneously with paralysis (Hellebrekers et al. 1990), making this agent acceptable in these species. Injection at a slow to moderate rate is recommended to avoid dysphoria or onset of paralysis before unconsciousness (Leary et al. 2013). Relay toxicity to scavengers may occur (Leary et al. 2013). T-61 is no longer available in the United States. Embutramide is a DEA Schedule III controlled drug in the United States, but T-61 is not controlled in many countries and therefore may be available. The dose extrapolated from small animals is 0.3 ml/kg IV (Hyman 1990). T-61 has been used as a component in multistep euthanasia procedures in fin whales (Daoust and Ortenburger 2001; Dunn 2006) and a southern right whale (*Eubalaena australis*; Kolesnikovas et al. 2012). Doses have been 100 ml for a 10.5 m fin whale (9.5 ml/m or ~0.015 ml/kg; Daoust and Ortenburger 2001), 120 ml for a 13.5 m fin whale (8.9 ml/m, or ~0.01 ml/kg; Dunn 2006), and 750 ml for a 14 m southern right whale (54 ml/m, or ~0.02 ml/kg; Kolesnikovas et al. 2012).

Potassium Chloride

Saturated potassium chloride (KCl) solution is acceptable in a two-step or multistep euthanasia procedure when preceded by unconsciousness or general anesthesia, though not as a sole euthanasia agent (Leary 2013). The mechanism of action is cardiotoxicity. Q2 It is not a controlled substance; it is inexpensive, does not induce histologic artifacts, can be mixed in the field, and is a preferred technique to reduce risk of relay toxicity (Leary 2013). Arching and gaping commonly occur, and muscle spasms may occur despite premedication rendering the animal insensible (Dunn 2006; Leary 2013; Harms et al. 2014). Rapid IV or intracardiac injection at 1–2 mmol/kg (75–150 mg/kg) causes prompt cardiac arrest (Leary 2013). Commercial medical-grade products are supplied at a 2 mmol/ml (150 mg/ml) concentration (Plumb 2015), which can result in impractical large volumes for larger animals. Higher concentrations can be mixed, with temperature-dependent solubility: 281 mg/ml at 0°C, 360 mg/ml at 25°C (Lide 2004). Even higher concentrations can be achieved by mixing KCl in hotter water, but in cold weather, KCl salt may precipitate in tubing as the highly saturated solution cools, thereby blocking administration and negating the advantages of faster dissolving and higher concentrations. For practical dose and volume calculation purposes, saturated KCl solution at ambient temperatures can be considered to be approximately 4 mmol/ml or 300 mg/ml, or double the concentration of commercial solutions. For example, a 10,000 kg whale dosed at 1–2 mmol/kg (after heavy sedation and analgesia) would require 2.5–5.0 L saturated KCl solution to complete euthanasia. These volumes can be accommodated in pressurized plastic canisters adapted for the purpose, as described above for intracardiac injections (**Figure 28.5**). Intracardiac KCl solution has been administered in four mysticete whales in this dose range following premedication with midazolam, acepromazine, and xylazine (Harms et al. 2014), and has been used subsequently in additional cases, including large odontocetes (*Kogia* spp.), as a means to minimize relay toxicity hazard when carcass disposal options were limited or lacking (Harms pers. comm.). It has also been employed at substantially lower doses (0.12 and 0.25 mmol/kg, or 9 and 19 mg/kg) in two other mysticete cases with different premedications that included T-61 and other drugs (Daoust and Ortenburger 2001; Kolesnikovas et al. 2012).

Paralytics

Paralytic agents have been reportedly used in stranded marine mammals, primarily because these drugs are not all controlled substances. The mechanism of action involves muscle paralysis, respiratory restriction, and hypoxia induction. Animals that have received paralytics as euthanasia agents without premedication suffocate while maintaining consciousness. This process can be slow and prolonged in diving species that can withstand long periods of apnea. Hyman reported (1990) using potassium chloride with succinyl choline to induce cardiac arrest and thereby shorten the period paralytics may take to induce death; however, neither of these drugs is an acceptable euthanasia agent in a conscious animal due to the expectation of fear, struggling, or pain before death occurs (Leary et al. 2013). The amounts required for a large marine mammal also could pose a life-threatening risk to personnel in the event of accidental injection. Paralytic agents should not be used unless a person trained in treatment of paralytic drug accidents and an appropriate first-aid response kit are present.

Inhalants

Inhalant anesthetic agents such as sevoflurane, isoflurane, enflurane, desflurane, halothane, and methoxyflurane are considered humane methods of euthanasia (Leary et al. 2013). Halothane and methoxyflurane are no longer clinically available in the United States but are still available in some countries. These agents are more easily applied for euthanasia of captive animals, smaller animals (sea otters, pinnipeds), or animals already anesthetized. As sole euthanasia agents, they are only recommended for animals less than 7 kg, even though conditionally acceptable for larger animals; this is because of cost and difficulty of administration (Leary et al. 2013). Disadvantages of inhalant anesthetics are the specialized delivery systems required for administration, the extended period of time required for induction in breath-holding species, and the prolonged physical restraint necessary. These disadvantages are both risky to personnel involved as well as stressful for the animal; unless the animal is markedly debilitated or sedated, there is a potential for irritation or aversion during inhalation induction, the potential for a vigorous excitement phase, and increased exposure hazards to personnel. Isoflurane liquid delivered in repeated small portions at peak inspirations directly to the blowhole of a premedicated juvenile right whale after expending all available injectables appeared to achieve aerosolization in the inrush of air, and a reduction in palpebral response, but also may have been irritating, did not achieve anesthesia, and is not a particularly recommended methodology (Harms et al. 2014).

Carbon dioxide, delivered in a closed chamber, is commonly used for euthanasia of laboratory animals. Carbon dioxide concentrations must reach levels high enough to induce unconsciousness and subsequent death. It is doubtful that these levels would be reached quickly in breath-holding animals or in species with adaptations to high concentrations of carbon dioxide. Carbon dioxide has also caused an excitatory phase before death in cats and dogs, is not recommended in species larger than a cat, and may not be as painless as previously believed (National Research Council 1992; Close, Banister, and Baumans 1997; Leary et al. 2013).

Physical Methods

Several physical methods of euthanasia have been employed in marine mammals. For a physical method of destruction to be considered humane, it must fulfill the requirement of rapidly inducing relatively painless unconsciousness before death (Leary et al. 2013). Only methods that quickly and relatively painlessly destroy the brain or brain stem are considered humane methods of euthanasia. All other physical methods of euthanasia (e.g., exsanguination, suffocation, bilateral thoracotomy, gunshot to heart) are considered humane only if used in a heavily sedated, unconscious, or moribund animal, or as a secondary confirmation of euthanasia.

If properly performed, physical euthanasia is very rapid, requires less handling, and may induce less fear and anxiety than chemical methods. There are no drug residues to put scavengers at risk and no controlled drug restriction issues, unless premedication is used to reduce anxiety prior to the physical method. No veterinary training is required, although knowledge of the target anatomy is essential. Physical euthanasia methods are typically lower in cost than chemical methods. And in mass stranding events, physical methods may be the only practical options, apart from letting nature take its course or basic hospice care. However, if performed incorrectly, physical euthanasia methods can dramatically increase rather than relieve suffering. In addition, there may be personnel and public safety risks inherent in utilizing lethal force trauma for euthanasia, animal brain destruction that can preclude critical postmortem analysis, potential lead residue hazards to scavengers, and necessary firearms and/or explosives training, as well as and adverse aesthetics and methodologies triggering unfavorable public response. Hampton et al. (2014b) noted that "…chemical euthanasia methods cannot generate instantaneous deaths and are invariably associated with prolonged time to death…. There is a compelling argument that the shortest time to death should be the overwhelming priority for euthanasia methods, over concerns such as public acceptance or aesthetics." While there is considerable merit in physical methods of euthanasia when properly applied, this assessment fails to take into account that with chemical euthanasia, each successive premedication incrementally relieves suffering while a single inappropriately applied physical method can increase suffering dramatically. It also overlooks the requirement of public support for stranding response organizations, whether funded from governmental or private sources. Public perceptions cannot be lightly dismissed for any method of euthanasia employed; engagement, discussion, and education can and should be employed to guide public perception and understanding, yet the need for euthanasia of the animal takes priority over that of the observer.

Ballistics

A scientific approach to the use of ballistics has not been reported in polar bears, pinnipeds, walruses (*Odobenus rosmarus*), or sea otters; however, the anatomy of the target organs for euthanasia of these species is not markedly different from terrestrial mammals, and diagrams published for domestic animals can be adapted (Leary et al. 2013). If done correctly, ballistics should cause instantaneous unconsciousness (i.e., instant destruction of the brain or brain stem), followed by respiratory and cardiac arrest. Although brain destruction results in immediate unconsciousness, tetanic spasms and hindquarter movements can occur for several seconds (Leary et al. 2013). When ballistics are used in field conditions, the caliber of the firearm should be appropriate for the species. Personnel should be trained to hit specific target organs (brain, brain stem, heart, neck), including practice on deceased animals. When the brain or brain stem is destroyed by gunshot, consciousness is lost instantaneously, and the definition of euthanasia is met (Leary et al. 2013). In field situations, a clean head shot may not be possible, however, and a neck or heart shot may be the only option for humane killing when criteria for euthanasia cannot be met, or when the brain is required for diagnostic purposes (e.g., rabies, domoic acid). Heart and neck shots may also be used as the last step of a multistep euthanasia procedure.

Ballistics have been evaluated for euthanasia of cetaceans. Several anatomical characteristics in cetaceans make the use of ballistics challenging. Skin, blubber, and muscle of the forehead (melon) are arranged such that kinetic energy from a projectile is absorbed, dampening the impact. The anterior (frontal) surface of the cetacean skull is concave with extensive sinuses, increasing the likelihood of further bullet deflection (Barzdo and Vodden 1983). The extensive muscle on the nuchal, parietal, and occipital regions of the skull makes occipital shooting ineffective in larger animals. Thick, dense blubber and tough, intermuscular fascial planes of large whales can redirect the trajectory of the spinning projectile away from its intended target. Use of ballistics in mass strandings can be distressful to the surviving animals and to personnel responding to the event. Exposure to the noise, visual destruction, agonal vocalizations, and possible release of pheromones by frightened animals may exacerbate anxiety and fear in the conscious animals (National Research Council 1992), although this distress could potentially be alleviated by administration of sedatives, or suppressors (silencers) where legal, and must be weighed against the suffering entailed with no intervention.

In smaller cetacean species (variously considered less than 4–8 m in size, depending on the cited source and the equipment used), there are two different documented approaches. The first is a shot aimed through or just caudal to the blowhole at a 45° angle directly down and back (ventrocaudally) to an area behind the pectoral flippers (Geraci and Lounsbury 2005; Hampton et al. 2014a,b). The second is a horizontal shot lateral to the brain, just above (dorsal to) the center of the eye–ear line (RSPCA 1997, 1998; Geraci and Lounsbury 2005; Barco et al. 2016). Aiming through the melon from the front of the skull is not recommended because of the depth of soft tissues that must be penetrated and the ricochet potential from the thick parabola-shaped frontal bones. The Western Australia Department of Parks and Wildlife recommends three quick successive shots close together along the animal's long axis starting just caudal to the blowhole (Hampton et al. 2014a). The firing range should be 0.4–1.0 m from the head (Geraci and Lounsbury 2005; Blackmore et al. 1995; RSPCA 1997; Hampton et al. 2014b). Bullets shot at point-blank range are subjected to greater yaw when penetrating the thick soft tissue that surrounds a cetacean skull, and if the muzzle touches the target, back pressure risks a burst barrel (RSPCA 1997; Geraci and Lounsbury 2005). Shooting cetaceans through the thorax is not recommended, as this will likely result in persistent consciousness and a slow death (Geraci and Lounsbury 2005).

There are conflicting reports on the type of firearm to use in these smaller cetaceans. The RSPCA's *Stranded Cetaceans: Guidelines for Veterinary Surgeons* (1997) states that a shotgun or a .22-caliber rifle should never be used. A shotgun with buckshot or a .22-caliber projectile may not reliably penetrate the skull. However, in a study performed on carcasses of a common dolphin and five pilot whales (≤18.7 ft.; ≤5.7 m) using a 12-gauge shotgun with a 28 g lead slug or buckshot (nine individual pellets totaling 28 g), the authors concluded that shooting cetaceans less than 4 m in length was effective, with the added safety feature that the projectiles did not exit the carcasses (Blackmore et al. 1995). Bullets that are solid or jacketed, blunt-tipped, nondeforming, a minimum of .30 caliber, and a minimum of 140 grains (9.8 g) are recommended (RSPCA 1997; Geraci and Lounsbury 2005; Hampton et al. 2014b). Hollow or soft bullets do not reliably penetrate the skull. Recent work on cadavers of multiple cetacean species found that 0.300/0.308-caliber 12 g/180 grain hydrostatically stabilized blunt nondeforming copper-alloy solid bullets achieved a stable trajectory and reliably penetrated the skull (Hampton et al. 2014b). This study forms the basis for the Western Australia Department of Parks and Wildlife's protocol for euthanasia of cetaceans <7 m in length by firearms (Hampton et al. 2014a) and may be applicable for larger cetaceans following cadaver testing (Hampton et al. 2014b).

High-powered rifles pose a risk to humans when used on rocky beaches, where ricochets of penetrating bullets may occur. A safe and humane shot with a high-powered rifle requires someone who is trained and adequately skilled to destroy the brain accurately and rapidly kill the animal.

The use of normally available ballistics in larger whales is challenging and not recommended in whales larger than 7–8 m, sperm whales (*Physeter macrocephalus*) of any size, or baleen whales other than minke whales or small juveniles, due to the anatomy of the head and blowhole (Barzdo and Vodden 1983; Needham 1993; Geraci and Lounsbury 2005; IWC 2010; IWC 2014). The brain is deeply buried in these larger cetaceans. For any projectile to be effective, it would need to penetrate approximately 1.2 m of blubber, muscle, and bone, and still maintain enough kinetic energy to destroy the brain and cause immediate unconsciousness and death. Highly public failures of attempted euthanasia of whales >8 m by firearms have occurred; in one case, the bullets were found to have tracked well off trajectory through the thick, dense blubber. In South Africa, euthanasia by firearms (0.375-caliber full metal jacket) has occasionally been judged successful in mysticete whales up to 12.3 m in body length but also unsuccessful in an 8.4 m humpback whale (IWC 2014). Further testing on cadavers is highly recommended prior to employing specific firearms and ammunition for euthanasia of whales larger than 7–8 m, as is publication of both successes and failures in use of firearms.

The Department of Conservation in New Zealand (Marsh and Bamber 1999) has reported the development of a specialized round and firearm for the humane euthanasia of sperm whales. They describe a specially designed 14.5 × 114 mm antiaircraft, 61 g, 12 L14 lead alloy bore-riding bullet with a flat tip. A firearm was also extensively modified to use this round effectively. The result was an 11.8 kg firearm that had a 2.4 m recoil, which must be operated standing sideways. Operators require training and practice to prevent serious injury to themselves. In field studies, two sperm whales were euthanized. One whale died after a single shot, and the second was rendered insensible by the first shot. In the second instance, a second shot gave the appearances of a dead whale, but the animal resumed breathing for another 2.5 hours. Although successfully employed on additional occasions since (IWC 2014), this sperm whale euthanasia device has not gained wide acceptance.

When considering ballistics for euthanizing cetaceans, three main components must be evaluated: (1) the size and anatomy of the animal; (2) the firearm and projectile to be used; and (3) the skill of the marksman. If any of these variables are less than ideal, then ballistics should not be used. In the RSPCA's *Stranded Cetaceans: Guidelines for Veterinary Surgeons* (1997), the authors suggest that it may be more humane to leave the animal to die on its own rather than applying any substandard method of euthanasia, especially in larger whales like sperm or baleen whales. The gravitational weight on the internal organs will likely induce a more humane death than repeated rounds of projectiles fired inaccurately, but may take a prolonged time (RSPCA 1997).

Explosives

Explosives have been used in attempts to euthanize larger whales that are difficult to euthanize by other means. These methods have been considered less acceptable, unacceptable, or simply unfavorably received, because of the tremendous soft-tissue damage, excessive noise, required expertise in the application of explosives (i.e., human safety factor), and lack of reliability in some applications. The infamous exploding whale video, recording a large whale carcass disposal situation in Oregon, USA (see account in Geraci and Lounsbury 2005), cannot be equated to euthanasia per se, because this disposal method was used for an already dead whale; nevertheless, it did cast a pall on the public's perception of the use of explosives in large whales. The RSPCA in 1997 and 1998 strongly discouraged the use of explosives. Recent advances have refined the technique considerably, however, and the AVMA considers the Coughran, Stiles, and Mawson (2012) explosive charge technique an acceptable method of euthanasia for stranded cetaceans when applied by a skilled and knowledgeable operator, assuming safety measures can be ensured (Leary et al. 2013). In fact, the instantaneousness of this technique is highly effective.

There are two different techniques for using explosives. A charge can be placed externally, caudal to the blowhole, and sandbagged to direct the shock wave down toward the brain (cranial implosion, implosive decerebration; Coughran, Stiles, and Mawson 2012). Alternatively, a charge can be placed inside the mouth (by a pole) at the base of the brain (Needham 1993; Geraci and Lounsbury 2005). The positioning inside the mouth must be accurate, since the impact of the blast decreases rapidly with distance. Water-gel explosives (e.g., Powergel Magnum) are recommended based on their stability (relative safety) and availability for civil engineering uses (Coughran, Stiles, and Mawson 2012). The whale must be stable (i.e., not rocking in the surf) in order that the charge not misdirect when detonated, and heavy equipment such as a bulldozer may serve a dual purpose of anchoring a stabilizing harness and providing a blast shield for personnel. Electronic communication devices and overflying helicopters must be restricted from the area to prevent premature detonation. Careful calibration of the charge is necessary to deliver sufficient force to kill the whale instantly, while at the same time not causing a visually disturbing massive crater or potential collateral damage (e.g., nearby window breakage). Explosives lie outside the usual skill set of veterinarians and marine mammal biologists; therefore, this is a procedure that must include properly trained and certified explosives experts. The reader is referred to Coughran, Stiles, and Mawson (2012) for additional important technical details. While not necessarily requiring veterinary expertise, the technique could benefit from the use of sedatives in the animal, especially when operating heavy stabilizing equipment near the whale and working in close contact to place the charges. Although effective and humane when properly performed, expect to receive limited to little public acceptance or comfort regarding these explosive charge techniques.

Penthrite grenade harpoons used in commercial and subsistence whaling have limited application for euthanasia or humane killing of large whales, where such equipment exists (Greenland, Iceland, Japan, Norway, and Alaska, USA) and where their use is culturally accepted (IWC 2014; Barco et al. 2016). Despite major public perception concerns and geographically limited availability of equipment and expertise, time to death can be rapid, depending on whale size and targeting (Lambertsen and Moore 1983; Knudsen and Øen 2003), and is more acceptable than leaving stranded whales to linger in badly decomposing states (Daoust and Ortenburger 2001; Kolesnikovas et al. 2012; Harms et al. 2014).

Exsanguination

Exsanguination is suitable only in extreme circumstances and is an acceptable adjunctive euthanasia technique only in anesthetized or unconscious animals (Leary et al. 2013). Time to death can be prolonged (19–40 minutes in two documented instances; Barco et al. 2016), and the amount of blood can be disturbing to responders and onlookers alike. Exsanguination can be accomplished by severing major vessels in the ventral peduncle, although this technique involves personnel safety issues when attempted in large whales. Alternatively, major vessels in the axillary space and cranial to the heart can be severed with a long flat blade or whaling lance inserted through an intercostal space to produce intrathoracic bleeding to the same effect, but with less external bleeding (Barco et al. 2016). Spinal lancing (IWC 2014; Barco et al. 2016) is another whaling technique potentially applicable as an adjunctive, but not primary, euthanasia technique, in which the spinal cord and vertebral vessels supplying the majority of blood flow to the brain are severed.

Verification of Death

Death is commonly accompanied by terminal muscle activity, including limb or fluke movement, arching, and exhalation/vocalization. Cetaceans typically beat their flukes in a "last swim." Bystanders should be advised to expect these movements and that they occur after the animal has lost conscious perception. It is imperative that death be verified. The absence of a heartbeat is the only reliable confirmation of death in mammals; however, with large marine mammals in field situations, it may not always be possible to detect a heartbeat. If an intracardiac needle is used to deliver euthanasia drugs and left in place after the injection, the loss of cardiac excursions can be detected via the needle. A portable ECG can detect loss of cardiac electric activity even in large cetaceans. If there is any doubt about confirmation of death, a secondary physical means of euthanasia can be performed to ensure death (Close, Banister, and Baumans 1996). Physical methods include bilateral thoracotomy, exsanguination, and gunshot through the heart or brain.

Carcass Disposal

A thorough necropsy can both facilitate carcass disposal (smaller pieces) and complicate it (decreased ease of towing). Carcass disposal is less of a problem with most pinnipeds, otters, and small cetaceans but becomes problematic with large whales. In most cases, smaller carcasses can be transported for rendering, burial, composting, or incineration, or buried on site if heavy equipment is available. Disposal to landfill may be considered distasteful or lacking proper respect but is actually just another form of deep burial, and a properly lined landfill minimizes groundwater contamination that could occur from carcasses containing pentobarbital euthanasia solution. For large carcasses, options are limited: a carcass may be left alone; buried on site; towed to sea and sunk; or released, moved, composted, or rendered. Previous attempts to burn or blow up carcasses created more problems than solutions and are not recommended (Geraci and Lounsbury 2005). A carcass left on a remote beach will provide food for scavengers and will decompose with time, and those that are sunk at sea provide habitat and food for numerous marine species. However, if there is any concern about concentrations of euthanasia solution (particularly pentobarbital or ultrapotent opioids) in the carcass, disposal methods that allow scavenger access are not acceptable. When deep burial or natural decay on the beach, or burial at sea, is not practical, composting is the next best option.

Limited information is available on tissue residue levels of anesthetic and euthanasia drugs in marine mammal carcasses. Low and presumably nonhazardous tissue concentrations of pentobarbital were found in a preliminary study in three gray whales and a pilot whale euthanized with pentobarbital at an estimated 20–40 mg/kg (Greer and Rowles 2000). However, relay pentobarbital toxicosis to scavengers consuming euthanized animals has been documented (O'Rourke 2002; Campbell, Butler, and Lunn 2009), including one case where a dog feeding on a euthanized humpback whale became comatose, although the dog eventually recovered from the toxic effects with supportive care (Bischoff, Jaeger, and Ebel 2011). For this reason, euthanasia of marine mammals with pentobarbital-containing euthanasia solution is often ruled out by resource managers in protected areas such as national seashores, or near natural or aquaculture shellfish beds. A low-residue euthanasia technique in large whales using pre-euthanasia sedatives and analgesics (midazolam, acepromazine, and xylazine), followed by saturated KCl, was developed to meet the definition of euthanasia, while minimizing relay toxicity and environmental concerns associated with necessarily large drug quantities (Harms et al. 2014). Although this is a lower-risk (but not zero-risk) technique than using pentobarbital-containing euthanasia solution, it is still recommended that acepromazine and xylazine IM injection sites be trimmed from the carcass and safely disposed of, particularly when the bulk of the carcass must remain in place.

A carcass that is buried should be at a site approved by the local authorities or beach owners. The body cavity should be opened, and then buried deep, to ensure tissues are not reexposed and digging scavengers cannot find the carcass. Towing and releasing the carcass at sea is problematic, since bloated carcasses tend to float and may rebeach themselves at a later date or become a navigation hazard. Of about 10 gray whale carcasses towed out to sea in California in 2000, 6 returned to the beach (Cordaro pers. comm.). Cetacean carcasses should be towed by the tail, with the body cavity opened; carcasses, if hauled to sea, must be far enough offshore to prevent drifting back and have enough ballast attached to allow them to sink (Geraci and Lounsbury 2005). Carcasses that return to the beach can be costly (i.e., second disposal costs), produce negative public perceptions, and may significantly alter stranding statistics. Any carcass to be towed out to sea needs to be marked in some manner, such as tail fluke or lateral thoracic notching, so that it can be recognized as a previously stranded animal.

Alternatively, an animal can be moved to another site for further study or more appropriate disposal. Some carcasses may need to be cut into smaller pieces for adequate disposal. Rendering plants, commercial incinerators, and veterinary schools may accept marine mammal carcasses. Composting remains a good-land based disposal option, too (Early et al. 2008). It is important to set up these coordinated plans for carcass disposal with colleagues and local agencies prior to an actual event occurring. Commercial trade in marine mammal parts is prohibited under the US Endangered Species Act and the US Marine Mammal Protection Act; therefore, carcasses or parts of carcasses cannot be sold.

Conclusions

Euthanasia is difficult. It is emotionally hard and often physically demanding to euthanize a marine mammal. Deciding to euthanize an animal and carrying out the act are difficult decisions, where emotions must be suppressed in order to work as efficiently and humanely as possible. Even though we know we are relieving animal suffering in accordance with the veterinarian's oath, and we know, as well, from experience and training, that this is the best (or least bad) option available for the animal, it can still take a toll. Do not hesitate to ask for, give, and accept support, internally or from outside sources, for yourself and for those who are working with you in these emotionally charged circumstances.

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Q2: Should this be "Leary et al. 2013"? if not then please provide complete information for "Leary 2013".