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Treatment of Canine Tooth Fractures in the Northern Elephant Seal (*Mirounga angustirostris*): Three Cases

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Abstract

The Marine Mammal Center (TMMC) in Sausalito, California, rescues, rehabilitates, and releases hundreds of stranded northern elephant seals (*Mirounga angustirostris*) each year. Common causes for stranding include maternal separation, malnutrition, and trauma. Causes of trauma include shark bites, conspecific interactions, and anthropogenic factors. Several cases of fractured teeth, secondary to presumed trauma, are presented to the center each year. This case series describes surgical approach and treatment of 3 young northern elephant seals that were admitted to TMMC for rehabilitation with tooth fractures with pulp exposure of maxillary or mandibular canine teeth. All 3 seals were successfully released into their natural environment.

Keywords

elephant seal, pinniped, marine mammals, tooth fractures, dentition, extractions, surgery, veterinary dentistry

Introduction

The elephant seal is the largest member of the family *Phocidae* or "true seals."[1,2] The range of the northern elephant seal (*Mirounga angustirostris*) is throughout most of the eastern Pacific Ocean, from Baja, California, to the Gulf of Alaska and the Aleutian Islands, with rookeries located primarily along the central California coast. They are second in size only to its southern relative (*Mirounga leonina*)[2] and were hunted to the brink of extinction in the late 1800s.[1] With federal protection, there has been recovery of the species which now includes over 200 000 seals.[1,3] There are marine mammal rescue centers along the western coast of the United States that rescue and rehabilitate sick and injured northern elephant seals, with the goal of releasing them to their natural environment. Typically, those admitted for rehabilitation are malnourished pups and weanlings. Parasitism, respiratory disease, skin disease, and toxicities are also common presentations.[4] Injuries from shark attacks, trauma from larger seals, entanglement in garbage, and storm-related injuries are often seen. Oral trauma and fractured teeth can occur.[4]

Treatment options for fractured teeth in pups and weanlings may be limited due to their tooth structure which consists of a wide pulp chamber and root canal, thin dentin, and an open apex. This article describes 3 cases of northern elephant seals that presented to The Marine Mammal Center in Sausalito, California, a rehabilitation center, treated with exodontia for fractured teeth and subsequently released into their natural environment.

Case 1

A 72.5-kg female weanling was admitted at approximately 11 months of age for the treatment of malnutrition, a subcutaneous (SC) abscess on her trunk, and a gingival mucosal draining tract over a fractured left maxillary canine tooth (tooth 204 according to the modified Triadan system).[5] Antibiotic therapy was initiated with amoxicillin/clavulanic acid,[a] 12.5 mg/kg orally twice a day. A complete blood count (CBC) and chemistry panel were within acceptable range according to published normal ranges for elephant seals.[6,7] During the initial phase of her treatment, she was eating well, gaining weight, and exhibiting age-appropriate responses. Surgical extraction of the fractured tooth was scheduled. A physical status of II was assigned, according to the American Society of Anesthesiologists (ASA) classification scale.[8] The patient was fasted for 12 hours prior to the procedure.

Tiletamine-zolazepam[b] was administered intravenously (1 mg/kg IV), via the extradural vein, and heavy sedation was apparent within 5 minutes postinjection. Oxygen and isoflurane[c] were delivered by mask to deepen the level of anesthesia

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for endotracheal intubation. A size 14-mm cuffed Murphy-type silicone endotracheal tube[d] was placed and the cuff was inflated until manual positive pressure ventilation (PPV) to a pressure of 20 cm H_2O confirmed an appropriate seal. Anesthesia was maintained with oxygen, at 50 mL/kg/min and 1.0% to 1.5% isoflurane inhalant via mechanical ventilation.[e] Intravenous access was maintained via the extradural sinus and fluid therapy with a balanced electrolyte solution[f] initiated at 10 mL/kg/h. Physiologic parameters including end-tidal carbon dioxide, peripheral capillary oxygen saturation, electrocardiogram, respiratory rate and quality, heart rate, and temperature were monitored. Mucus membrane color and capillary refill time were also monitored. Normothermia was maintained using a forced air warming device.[g] A local infiltration block of 0.8 mL 0.5% bupivacaine[h] was placed circumferentially subgingivally and submucosally around tooth 204. An injection of sustained release buprenorphine,[i] 0.12 mg/kg SC was given for pain management.[9,10]

The anesthetized oral examination confirmed a fractured tooth 204, with minimal crown remaining and pulp exposure. Purulent discharge was seen from within the alveolus and the root canal with abundant granulation tissue covering the exposed pulp (Figure 1A). Intraoral radiographs were obtained with a phosphor plate system[j] and a handheld X-ray generator.[k] Radiographs revealed minimal crown present at the gingival margin of tooth 204 and a longitudinal fracture extending apically through 30% of the root. The root canal was wide with age-appropriate thin dentin walls.[2,11] There was a radiographic lucency that included tooth 204 and the left maxillary first premolar (also referred to as the first postcanine tooth, tooth 205; Figure 1B). The radiograph in Figure 1C and the chart in Figure 1D depict the normal dentition of the elephant seal and the orientation of the premolar teeth.

A dilute chlorhexidine gluconate solution (0.12%)[l] was used to cleanse the mouth. A sulcular incision from the mesial aspect of tooth 204 to the distal aspect of tooth 205 was made to create a mucogingival envelope flap. The flap was elevated with a periosteal elevator.[m] The alveolus of tooth 205 was confluent with the canine tooth alveolus, which is common in elephant seal dentition and thus included in the periapical pathology. A simple single-rooted tooth extraction was performed to remove tooth 205. The canine tooth fragments were removed utilizing small animal sizes 5 through 8 luxators, elevators, and extraction forceps[n] (Figure 2A). A large amount of soft tissue was removed along with the fragments (Figure 2B). The alveoli were curetted and the alveolar margin was smoothed. Sterile saline was used to flush any remaining debris from the alveoli. Postoperative radiographs confirmed complete removal of tooth 204 and tooth 205 (Figure 2C). The mucogingival flap was further elevated and the granulation tissue debrided. The periosteum of the mucosa was incised to relieve tension and allow for a tension-free flap closure. The incision was closed with 4-0 poliglecaprone 25 suture[o] in a simple interrupted pattern (Figure 2D).

The patient was recovered in a surgical holding pen with no complications. She was offered her normal meal of fish and ate well several hours following recovery. Amoxicillin–clavulanic acid[a] was continued for a week postoperatively and the sustained release buprenorphine[i] for pain control was considered adequate for 3 days in the postoperative period.[9,10] An oral examination 2 days postoperatively revealed a partial dehiscence of the gingival incision at the mesial aspect (Figure 3). Subsequent daily examinations confirmed secondary healing of the extraction site. The patient continued to gain weight, was alert and active, and was released 2 weeks after surgery with a completely healed extraction site.

Case 2

A 74-kg male yearling of approximately 12 months of age was admitted for medical care of shark bite wounds and decreased body condition. He had sustained a complicated fracture of the first and second digit of the right front flipper and deep wounds on the right side of his neck and rear flippers. In addition, there was pulp exposure of the fractured right and left mandibular first incisor teeth (tooth 401 and 301, respectively). There was also pulp exposure of the fractured right maxillary canine tooth (tooth 104). Complete blood count and chemistry panel results were unremarkable, except for a mild eosinophilia. Oral tramadol[p] 4 mg/kg twice daily and ketoprofen[q] 1 mg/kg once daily were prescribed for pain management. A series of antibiotics, including ciprofloxacin[r] 15 mg/kg orally once daily and clindamycin[s] 5.5mg/kg orally twice daily, were also initiated upon admission. Surgical amputation of the first digit of the right front flipper due to osteomyelitis and extraction of the fractured mandibular incisors was performed by the veterinary staff 20 days following admission. Removal of fractured tooth 104 was postponed at the initial procedure to limit total anesthetic time. A second surgical procedure was scheduled to extract the canine tooth.

At the time of the second anesthetic procedure, the patient was assigned an ASA physical status of II based on normal admission blood work, general healthy appearance, and normal appetite and activity. The patient was immobilized with 1 mg/kg tiletamine–zolazepam via IV injection into the extradural vein. Endotracheal intubation was achieved with a 13-mm cuffed Murphy-type endotracheal tube. Anesthesia and monitoring proceeded in a similar manner as the previous case. Anesthetic complications included bradycardia, a restrictive breathing pattern, and hypothermia. A forced air warming blanket was used to correct the hypothermia. Blood samples obtained midprocedure revealed changes consistent with respiratory acidemia, pH of 7.258 (reference range: 7.31 $\pm$ 0.05) and pCO_2 of 68.1 (reference range: 43.9 $\pm$ 4.9), indicative of possible airway obstruction and/or restrictive respiration.[12] The possibility of an airway obstruction was addressed by extubation, clearing mucus from the tube, and reintubation. The restrictive breathing pattern and bradycardia were corrected by PPV with mechanical ventilation and administration of 2 doses of the inhalant bronchodilator albuterol[t] and 2 doses of 0.1 mg/kg ephedrine[u] IV. The remainder of the anesthetic procedure was uneventful and a subsequent blood

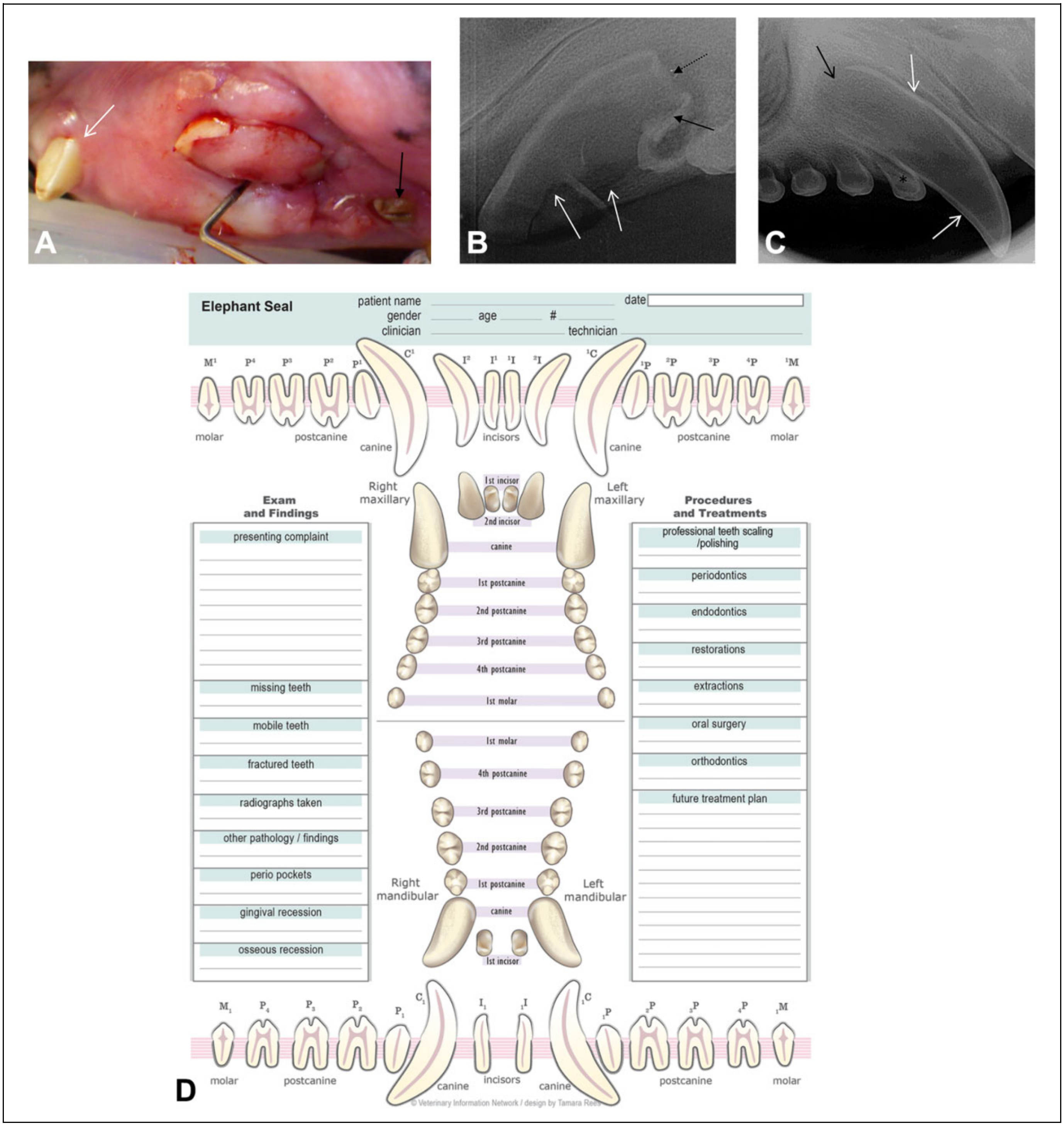

Figure 1. Fractured left maxillary canine tooth (tooth 204) in a northern elephant seal described in case 1. (A) Granulation tissue covering the exposed pulp of the remaining tooth. (B) Intraoral radiograph of tooth 204 prior to treatment. Note the longitudinal fractures of the crown extending into the root; possible fracture of the left maxillary first premolar (tooth 205). (C) Intraoral radiograph of the clinically normal right maxillary canine tooth (tooth 104). Note the incompletely formed apex, thin dentin, and wide root canal of this weanling elephant seal. Note the normal radiographic appearance of single-rooted right maxillary premolar teeth (teeth 105-108). (D) Dental chart for the elephant seal (courtesy of Tamara Rees, Veterinary Information Network). Premolars are referred to as "postcanines."

analysis confirmed improvement of the acidemia. A local infiltration of 0.4 mL 0.5% bupivacaine was instilled circumferentially submucosally and subgingivally around tooth 104.

On oral examination, the crown of tooth 104 was present with a longitudinal crown–root fracture and pulp exposure (Figure 4A). The mandibular incisors were not present, having

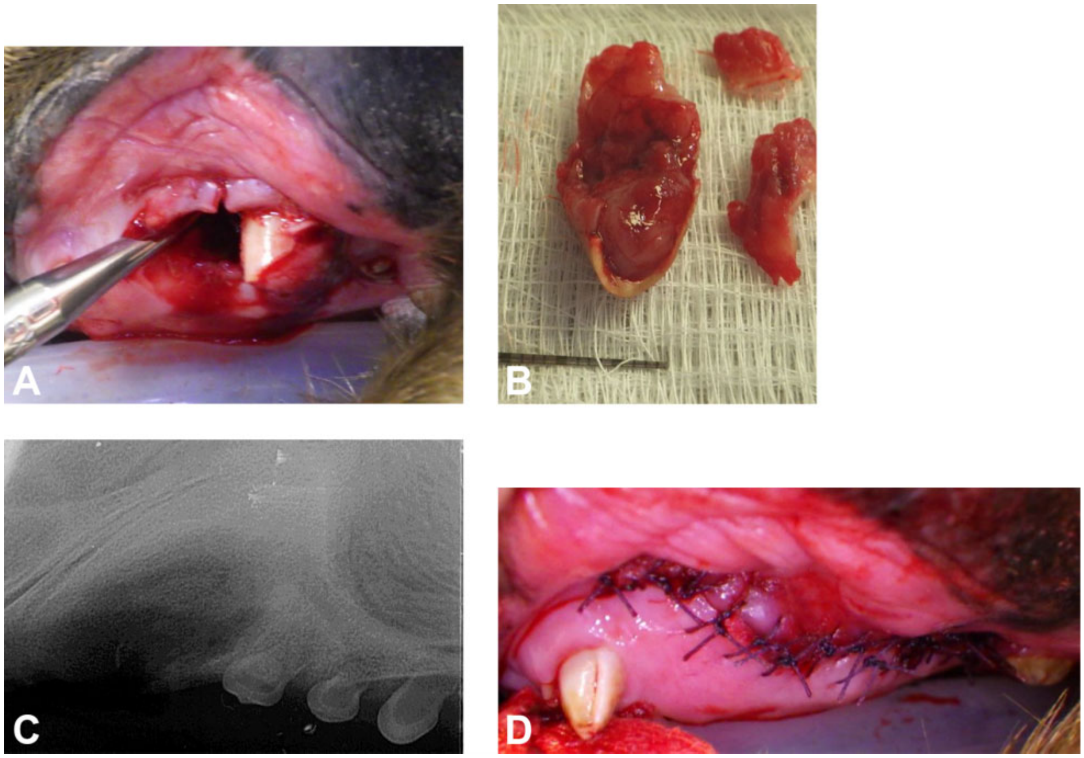

Figure 2. Treatment of tooth 204 in a northern elephant seal described in case 1. (A) Dental elevators were utilized to aid in the extraction of tooth 204. (B) Fragments of teeth 204 and 205 were removed. Note the extensive proliferative soft tissue within the root canal. (C) Intraoral radiograph after extraction of teeth 204 and 205. (D) Closure of the mucogingival flap with 4-0 poliglecaprone 25 in a simple interrupted pattern.

Figure 3. Same patient 2 days after surgical extraction of tooth 204 in a northern elephant seal showing partial dehiscence of the caudal incision line.

been removed during the previous surgical procedure, and healing was complete (Figure 4B). Intraoral radiographs of tooth 104, the first and second right maxillary premolars (teeth 105 and 106), and the mandibular incisor area were obtained (Figure 4C). Radiographs revealed an incomplete apex and thin dentin of tooth 104. There were 2 longitudinal crown–root fractures of tooth 104, which extended to the apical third of the root. A radiographic lucency was present at the apical portion of tooth 105.

A gingival incision was made from the mesial aspect of tooth 104 and extended past tooth 105. A releasing incision at the distal aspect of 105 was continued dorsally toward the mucosa. The flap was elevated and tooth 105 was removed. The crown of tooth 104 was removed in 3 pieces. The remaining intact wall of the root was extracted using elevators, luxators, and forceps. The alveoli were curetted and fragments of alveolar bone and tooth root were removed until a smooth alveolar wall was attained and complete removal of apical tissues and tooth fragments was achieved. Sterile saline was used to lavage the alveoli. Intraoral radiographs confirmed complete extraction of both teeth. The periosteum of the mucogingival flap was released and the flap was sutured with 3-0 poliglecaprone 25 suture in a simple interrupted pattern. In addition, a large mattress tacking suture was placed apical to the incision through the mucosa to the periosteum to aid in relieving any remaining tension (Figure 5A). An injection of 1 mg/kg ketoprofen was given intramuscularly and 0.12 mg/kg of sustained release buprenorphine was given SC. Recovery was unremarkable and the patient ate a meal of fish the evening of the procedure. Tramadol[p] and clindamycin[s] were continued post procedure. Inspection of the oral surgical site 2 days post procedure revealed good healing and an intact suture line. Six days postoperatively, a visual inspection revealed a small

Figure 4. Northern elephant seal described in case 2. (A) Complicated crown–root fracture of the right maxillary canine tooth (tooth 104). Note the close proximity of the right maxillary first premolar (tooth 105). Proximity of alveoli of these 2 teeth resulted in the need for extraction of tooth 105 along with tooth 104. (B) Rostral mandible after extraction of the incisors during a prior surgery. (C) Intraoral radiograph of tooth 104 prior to treatment. Note the longitudinal fracture lines extending into the root, thin enamel, and dentin of the immature tooth and the wide pulp chamber and root canal with an open apex.

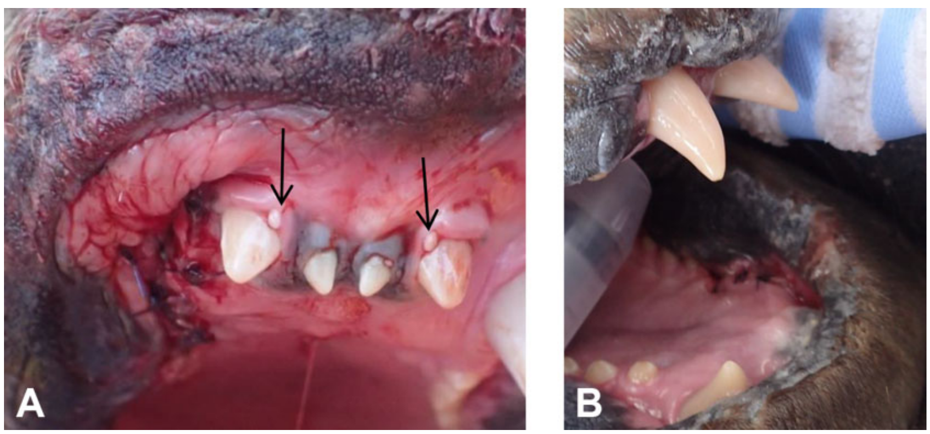

Figure 5. Elephant seal described in case 2. (A) Postsurgical extraction of tooth 104 and tooth 105 and closure of the mucogingival flap using 3-0 absorbable suture in a simple interrupted pattern and a mattress suture to aid in a tension-free closure. Note the persistent primary dentition. (B) Surgical site 1 week postoperatively.

opening of the suture line at the mesial aspect that appeared to be healing by secondary intention. The remainder of the incision remained closed and was healing well with no apparent discharge (Figure 5B). The patient was successfully released back to his natural environment 8 days after surgery with a completely healed surgical site.

Case 3

An 87.5-kg female yearling of approximately 12 months of age was admitted for treatment following apparent shark bite–related injuries. The intake examination revealed lacerations over her left tarsus with bone involvement; numerous lacerations on her body, head, and right axilla; and a fractured left mandibular canine, tooth 304, with pulp exposure. Clinically the patient was alert and eating a normal diet. A CBC and chemistry panel were performed at admittance were unremarkable. During rehabilitation, her condition declined and she became anorexic. The tarsal lesions progressed to osteomyelitis and a purulent discharge was noted from the fractured canine. Repeat blood work revealed an elevated white blood cell count, severe azotemia, hypernatremia, and significant hemoconcentration. These results were indicative of severe dehydration and sepsis. Antibiotic therapy included intramuscular injections of oxytetracycline[v] at 20 mg/kg every 4 days and enrofloxacin[w] at 10 mg/kg once daily along with supportive care; however, her condition continued to deteriorate. She subsequently received supportive care for several days, which consisted of IV fluids, tube feedings, and an addition of injectable clindamycin[x] at 5.5 mg/kg intramuscularly twice daily. Four weeks later, the patient was deemed sufficiently stable for anesthesia and the oral surgery procedure. Preanesthetic blood analysis was within acceptable parameters and she was assigned an ASA physical status of II. At the time of surgery, the patient's medications included the lincosamide, the fluoroquinolone, and carprofen[y] at 2.2 mg/kg orally twice a day. Anesthesia was performed in the same manner as the previous 2 cases. There were no anesthetic complications. She was given PPV manually due to mechanical ventilator malfunction. Intraoperative

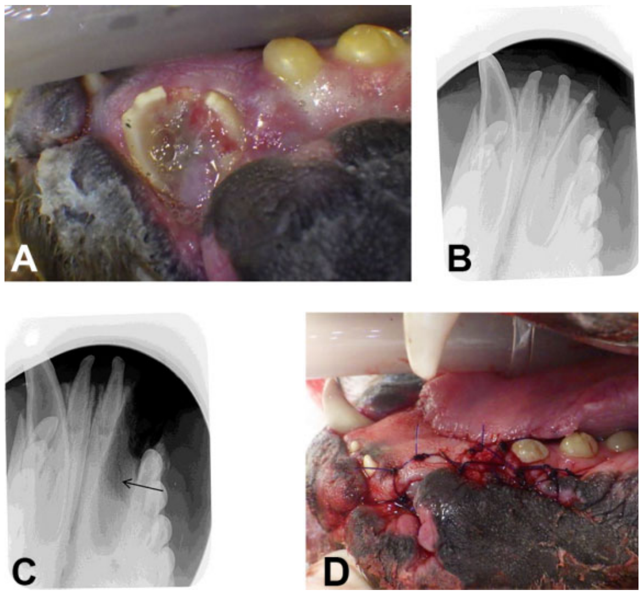

Figure 6. Elephant seal described in case 3. (A) Complicated crown–root fracture of the left mandibular canine tooth (tooth 304). (B) Intraoral radiograph of the rostral mandible showing an exposed pulp, widened periodontal ligament space, and missing crown of tooth 304. (C) Intraoral radiograph obtained after surgical extraction of tooth 304 and tooth 305. (D) Closure of the mucogingival flap with 3-0 absorbable suture in a simple interrupted pattern and mattress tacking sutures to aid in a tension-free closure.

injectable clindamycin[x] and a postoperative injection of carprofen[y] were also administered.

The anesthetized oral examination revealed increased scar tissue at the rostral lower lip with resultant defects in the lip margin. Tooth 304 was fractured at the gingival margin with a purulent discharge and granulation tissue covering the exposed pulp (Figure 6A). Intraoral radiographs confirmed longitudinal fractures of the root, minimal enamel and dentin of the remaining crown, an open apex with a wide pulp canal, a normal periodontal ligament space around the coronal two-third of the root, and a fracture line through the alveolus (Figure 6B).

A local infiltrative block, 0.75 mL 0.5% bupivacaine, was performed circumferentially around the root of tooth 304 and into the pulp canal. A sulcular incision was made circumferentially around the canine root and was extended distally to the left mandibular first premolar (tooth 305). The incision was extended apically to create a mucogingival flap. The flap was elevated as previously described. Tooth 305 was extracted as a single-rooted extraction to allow access to the canine tooth and due to a congruent alveolus with the canine. The remnants of tooth 304 were removed in sections with winged elevators, luxators, and extraction forceps. The remainder of the pulp tissue was curetted along with extensive granulomatous tissue. Intraoral radiographs confirmed extraction of both the premolar and canine (Figure 6C). The alveoli were curetted to remove the remainder of the granulation tissue and debris and then lavaged with sterile saline. A tension-free closure was difficult

Figure 7. Northern elephant seal, *Mirounga angustirostris*, after rehabilitation and release into the natural environment.

to obtain due to scar tissue formation from the rostral mandibular trauma. There was moderate hemorrhage from mucosal blood vessels and the granulation tissue at the lip margin where the defects occurred. Hemostats and direct pressure were applied to allow for clot formation and hemorrhage control. The flap was closed with 3-0 poliglecaprone 25 using cruciate and simple interrupted suture patterns. Two periosteal mattress sutures were placed mesially and distally to help relieve tension from the weight of the lip and nonelastic scar tissue (Figure 6D). The fracture of the alveolus was stable and required no treatment beyond the closure of the supporting tissues.

Recovery was smooth. Minor bleeding occurred postoperatively. Two hours postoperatively, the patient was bright, alert, responsive, and ate her normal meal later that day. Careful monitoring over the next few days confirmed cessation of the bleeding. Visual examination of the extraction site 2 days after procedure revealed partial dehiscence of the mesial section of the suture line with a healthy bed of granulation tissue at the dehiscence site. The patient remained on clindamycin[x] and carprofen[y] postoperatively. The patient was released to her natural environment 2 weeks after the oral surgery after healing of the surgical site (Figure 7).

Discussion

Malnutrition and trauma are the most common reasons northern elephant seals are admitted to marine mammal rescue centers. Pups may be separated from their mothers and washed off beaches during winter storms on the central and northern California coast, while weanlings may not have gained enough weight during their 4-week nursing period to survive.[1,13] Trauma to pups and weanlings can occur on beaches when aggressive males or protective females interact with the much smaller young animals.[1] Predator attacks, primarily sharks, and gunshot wounds are also significant causes of trauma. Fractured teeth can occur at any point during the initial insult or during the rescue, transport, and rehabilitation process. Captive placement of elephant seals deemed unlikely to survive after release is not a viable option, due to their large size, the cost of upkeep, and the difficulty in providing appropriate artificial environments. The fact that they are most likely released back into the wild limits the options for the treatment of dental injuries.

The dentition of elephant seals differs from most phocid species in that the "postcanine" teeth are minimally functional and there is pronounced sexual dimorphism.[2,11] These teeth are single-rooted or at times double-rooted and become peg-like with wear and abrasion of the thin enamel.[2,11] The difference between the premolars and molars can be minimal. Three different morphological types of postcanine teeth in the maxilla and mandible have been described.[2,11] Type I are single-rooted with rudimentary cusps, type II a, b, and c are single cusp, bicuspid, and tricuspid, respectively. Type III teeth are similar to the molar teeth in other pinnipeds.[2,11] The first premolar of male seals is frequently absent, possibly due to the competition for space with the much larger canine tooth.[2,11] The canine teeth of males are considerably longer with a wider diameter than females, and this sexual variance is evident in newborn pups.[11] The primary dentition is minute, nonfunctional, and is lost soon after birth.[11] The adult elephant seal has 30 teeth with a formula of Incisor 2/1, Canine 1/1, Premolar 4/3-5, Molar 1/1.[11] The pups have erupted all 30 permanent teeth by the time they are weaned.[11] There is some variation in this formula with supernumerary teeth, persistent deciduous teeth, and absent postcanine teeth.[2,11] The enamel layer in elephant seal dentition is relatively thin compared to the overall size of their teeth and compared to other large marine mammals.[11] The cause of extreme wear of the nonfunctional premolar and molar teeth is unclear at this time.[2]

The alveoli of the first premolars are generally confluent with the alveoli of the canines,[11] often necessitating extraction of the first premolar when the canine tooth is extracted. The apices of the teeth remain open for 7 to 12 years.[2,11] As very few adult and subadult elephant seals are ever maintained in captivity or rehabilitated, most dental work will likely be performed on stranded weanlings and yearlings with very thin enamel, thin dentin, wide root canals, and an open apex.

The dentition of the elephant seal reflects its use and the type of prey elephant seals feed on. Fifty-three species of prey have been identified in the elephant seals' diet. Squid comprise the majority along with Pacific whiting, rock fish, small sharks, and rays and occasionally crustaceans.[1] Canine teeth are used to grasp the prey and thrust it to the back of the throat where it is swallowed whole. The postcanine teeth have minimal function and are not strategic teeth. Loss of these teeth should have minimal effect on the seals' ability to forage for food.[2,11] The canine teeth in adult males are used but are not necessary for male dominance during the breeding season. It is more important for adult males to be aggressive, loud, experienced, and in excellent body condition for more proficient intraspecies threat and fighting displays, rather than possessing large teeth for biting.[1,2]

Extraction of complicated tooth fractures is the most common choice for immature elephant seals. Root canal therapy in many cases may not be feasible due to incomplete maturation. As was seen in the current 3 cases, the crowns were either missing or exhibited a significant longitudinal root fracture, making treatment options other than extraction not viable. Partial pulpotomy with pulp capping, multistep apexification procedures, or closure of an open apex utilizing mineral trioxide aggregate (MTA), and concurrent root canal therapy may not prove to be practical options for patients that are to be released into their natural environment in the most efficacious manner possible. Infectious diseases, iatrogenic-related injuries, and habituation to humans are minimized when the seals are released within the shortest possible time. Monitoring and follow-up will not be available for any patient that received a procedure to maintain a vital tooth. Failure of any of these procedures could result in a painful nonvital tooth, abscessation, and/or osteomyelitis.[14,15] Extraction of the first premolar teeth allows surgical access to the canine tooth root and is necessary when the premolar shares the alveoli with the damaged canine or is damaged by the original insult.

Tooth fractures, lacerations, abscesses, mandibular fractures, neoplasia, and periodontal disease have all been identified in the oral cavities of elephant seals.[2,14] Dental examination recognized other findings including supernumerary teeth, persistent deciduous teeth, attrition, abrasion, enamel hypoplasia, periapical disease, and malocclusion.[2] Intraoperative complications of exodontia appear to be minimal. The jaw bone of elephant seals is quite substantial. The skull is considerable due to expansion of the maxillary and nasal bones to accommodate the large canine teeth and proboscis.[11] Both are able to withstand heavy forces.[11] Evidence of periodontal disease has been seen in skulls of adult and juvenile seals and includes horizontal bone loss and a roughened alveolar margin.[2] In one study, evidence of a periapical lesion associated with a complicated tooth fracture was recorded in only one case out of 104.[2] Only 6 periapical lesions were identified in these skulls and signs of osteomyelitis associated with a periapical lesion were absent.[2] Thus, inadvertent fracture during exodontia of a weakened jaw bone from advanced periodontal disease is unlikely, unless there was an occult traumatic fracture or a neoplastic process already present prior to the surgery.

The most common postoperative complication of exodontia in elephant seals is dehiscence of the mucogingival flap. Environmental and behavioral issues, such as the artificial environment provided, diet, interspecies and intraspecies interactions, and heavy adipose rich tissues, contribute to the frequent dehiscence of surgery sites.[14] Elephant seals rapidly produce granulation tissue for secondary healing of any gaps that may occur in the suture lines.[16] Tension-free mucogingival flaps and tension-releasing stay sutures help to retain first intention healing. The heavy buccal mucosa and lips may result in tension on the incision line, especially at the mandibular sites. Mattress or cruciate suture pattern for closure may be superior to a simple interrupted pattern with regard to relieving tension and preventing dehiscence.[14] Suture material was chosen based on its tensile strength, duration of that strength, compatibility with the tissues, availability, and ease of use.[17] Most seals tolerate a wide range of suture material.[16] In all 3 exodontia cases, the authors selected an absorbable poliglecaprone 25 suture material. It may be more appropriate to have a reverse cutting needle swaged onto the suture material to allow for smoother penetration of the thick gingiva and the mucosa.[17] Absorbable suture is recommended to eliminate the need for a second anesthetic event for suture removal.[17] As with all animals, suture that remains intact for longer periods of time may irritate the oral tissues and become a source of an inflammatory response or infection.[17] Restriction of the seals from their water habitat can cause undue stress on the animals, as they require pools for feeding and thermoregulation.[14,16,18] Oral surgery sites will be exposed to the water environment and the food that is ingested by the patients. Oral tissues are quick to heal, even by second intention.[17] Tube feeding may be an option if there is concern with dehiscence of the incision due to a whole fish diet. However, this procedure could actually lead to further iatrogenic trauma of the surgery site from manual restraint and introduction of the feeding tube.

Common sequelae of complicated tooth fractures are stress-related illnesses due to pain, lack of appetite, loss of body condition, abscess formation, and osteomyelitis.[14,15] The chronicity of the open pulp chamber contributes to subsequent bacterial infections. Many stranded animals may have compromised immune systems secondary to malnutrition and illness. Thus, antibiotic use may be warranted for preoperative treatment and postoperative recovery, but not in lieu of surgical treatment.[15] Efforts should be made to limit the duration of antibiotic usage and choose appropriate drugs and doses. A recent study has identified resistant strains of bacteria in rehabilitated pups who had received antibiotic therapy, as well as those pups housed near them but had not been administered the antibiotics.[19] Although all antimicrobial medications are discontinued at least 5 days prior to release of the patients from rehabilitation centers, this study suggests that after release, those resistant strains could potentially be introduced into the wild population. Therefore, judicious use of antibiotics is indicated.

Complications related to anesthesia are also a concern in this species, particularly when they are undergoing prolonged surgical procedures. Northern elephant seals hold the record as the deepest diving pinniped, up to 2133 m, and have extreme breath-holding capability.[1,20] The dive reflex allows these mammals to remain submerged for as long as 2 hours and is characterized by a significant bradycardia, peripheral vasoconstriction, and a shunting of blood particularly to the brain and heart.[20-22] The reflex is primarily controlled by central nervous pathways that influence the respiratory drive center.[21] The sympathetic nervous system triggers splenic contraction, peripheral vasoconstriction, and sphincter contraction of the vena cava to increase the hematocrit and pool blood in the hepatic sinus.[21,23]

The unique physiology of the dive reflex, which is a conscious response, can make the diagnosis and treatment of anesthetic complications more difficult.[21] Anesthetic agents depress central cardiovascular and respiratory centers inducing apnea and can mimic the reflex.[20] Periods of apnea are not uncommon in anesthetized elephant seals and the bradycardia may not require treatment.[21] This normal occurrence must be differentiated from anesthetic-induced hypoxia.[20] Some anesthetic drugs lead to increased cardiac work load and oxygen demands and thus counteract beneficial aspects of the dive response.[20] Careful monitoring is required to differentiate the causes of apnea and bradycardia and thus the decision to institute treatment. Anticholinergic drugs such as atropine or glycopyrrolate for treatment of a bradycardia may increase myocardial oxygen demand and should be used with caution.[20] Additionally, in our experience, atropine administration in doses ranging from 0.02 to 0.1 mg/kg IV or intramuscularly is ineffective in reversing bradycardia in this species. Identifying the infraorbital canal or locating the inferior alveolar nerve in these large mammals can prove challenging, especially with the heavy layer of adipose-rich mucosa. The ease of the local infiltration circumferential anesthetic nerve blocks prompted their utilization in all 3 of the cases presented.

Elephant seals may be quite tolerant of elevated carbon dioxide levels during a natural dive; however, assisted ventilation is recommended to prevent atelectasis and hypercapnia.[21] Accurate noninvasive blood pressure measurements are unlikely to be obtained due to the thick blubber layer, peripheral vasoconstriction and shunting, and deep peripheral vasculature for cuff or transducer placement.[21] Direct arterial blood pressure measurements are rarely utilized due to lack of an easily accessible artery for catheter placement. Electrocardiogram, or at least an esophageal stethoscope, is strongly recommended for continuous cardiac monitoring as the blubber layer on the chest wall can muffle heart sounds, and the onset of bradycardia can be rapid.[21] Thermoregulation occurs through both behavioral adaptation and body condition, and thus, seals can become hypothermic or hyperthermic depending on physiologic conditions as well as the environment in the operatory.[21,24] Elephant seals also have countercurrent heat exchange systems in the peripheral blood vessels of the flippers and superficial skin layers.[24] Anesthetic drugs and the dive reflex can disrupt the normal function of this heat exchange system; therefore, constant monitoring of temperature via a more central location (esophageal or deep rectal) is recommended.[21]

Endotracheal intubation is essential to maintain normal ventilation of elephant seals during prolonged procedures, particularly when working within the oral cavity.[14,21,23] Relaxation of the large and flaccid pharyngeal and palatine tissues can collapse the trachea with its incomplete cartilage rings and lead to upper airway obstruction and can also complicate endotracheal intubation.[14,21,23] The rib cage is quite flexible in order to withstand the extreme external pressures elephant seals are subjected to during deep dives. Lack of a rigid thoracic structure can lead to compression of pulmonary tissue from body position and weight during the procedure and muscle relaxation while under anesthesia, thus causing pulmonary arterial blockage and perfusion mismatch.[21] It may also contribute to a restrictive respiratory effort, as noted in the second case presented. Assisted ventilation by manual PPV may not be sufficient to overcome this restriction; thus, mechanical ventilation is strongly recommended.[21] Intramuscular or SC injections may be slow to absorb with peripheral vasoconstriction and a thick layer of adipose tissue; therefore, IV access is preferred for drug delivery.[18] The extradural intervertebral vein is easily accessible for administration of fluids and medications. However, excessive vascular shunting, possibly due to the dive response, can create stasis of blood and thus lack of distribution of the drugs. Accidental injections into the blubber layer rather than the SC space or musculature have been identified as the cause of some sterile abscesses in elephant seals.[18] Antibiotic choice was based on availability, appropriate concentrations, ease of administration, and broad bacterial spectrum of efficacy to cover the varied species of oral flora. Elephant seals are able to tolerate a wide range of antimicrobial drugs.[16,25]

Conclusion

Traumatic dental injuries in northern elephant seals can be successfully treated with proper anesthetic protocols, knowledge of their dentition and anatomy, and an understanding of the unique requirements during surgery and the postoperative recovery. Treatment options must address the circumstances that the elephant seals are to be released back into their natural environment, minimal rehabilitation time is desired, and long-term postoperative monitoring will not be possible. The treatment plan must take into account their intraspecies and feeding behavior and insure that the dental repair does not compromise their ability to be a productive member of the colony or decrease their foraging capabilities. More dissemination of the knowledge that currently exists and continued active research will further our understanding of medical conditions of and treatments for this species.

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Materials

a. Clavamox, Zoetis, Parsippany, New Jersey.
b. Telazol, Zoetis, Kalamazoo, Michigan.
c. Isoflurane, MWI, Boise, Idaho.
d. Silicone Cuffed Endotracheal Tube, Jorgensen, Loveland, Colorado.
e. Ventilator, Hallowell EMC, Model 2002IEPro, Pittsfield, Massachusetts.
f. Lactated Ringers, Hospira Pfizer, New York, New York.
g. Bair Hugger, Model 505, Arizant Healthcare Inc, Eden Prairie, Minnesota.
h. Marcaine, Hospira Pfizer, New York, New York.
i. Buprenorphine SR, ZooPharm, Laramie, Wyoming.
j. CR7 Dental Digital Radiography, IM3, Vancouver, Washington.
k. Nomad PRO, Airbex, Charlotte, North Carolina.
l. C.E.T Oral Rinse, Virbac, Carros, France.
m. Molt #9, Cislak Zoll Dental, Niles, Illinois.
n. Exodontia Pack, Cislak Zoll Dental, Niles, Illinois.
o. Monocryl, Ethicon; Johnson and Johnson, New Brunswick, New Jersey.
p. Tramadol, Sun Pharmaceutical Industries Ltd, Cranbury, New Jersey.
q. Ketoprofen, Ketofen Zoetis, Parsippany, New Jersey.
r. Ciprofloxacin, Rising Pharmaceuticals Inc, Allendale, New Jersey.
s. Clindamycin, Lannett Company Inc, Philadelphia, Pennsylvania.
t. Albuterol Sulfate 90 μg/puff, ProAir HFR; Teva Respiratory, North Wales, Pennsylvania.
u. Efedrine injectable, Patterson Medical, Warrenville, Illinois.
v. Oxytetracycline injectable, Norbrook Inc, Lenexa, Kansas.
w. Enrofloxacin injectable, Bayer Healthcare LLC, Shawnee Mission, Kansas.
x. Clindamycin injectable, Alrogen Inc, Pinebrook, New Jersey.
y. Rimadyl, Zoetis Inc, Kalamazoo, Michigan.

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