Case Report

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Case Report

Sugammadex and Acceleromyography Used During a Lensectomy in a Sea Lion

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Simple Summary: Simple Summary

Eye surgery is a relatively common procedure in older sea lions in captivity. In this case, a sea lion underwent intraocular surgery to remove a bilateral cataract. A neuromuscular blocking agent (rocuronium) was given to guarantee a central eye position during surgery, and at the end of surgery, a reversal agent (sugammadex) was used for the first time in this species to quickly reverse the neuromuscular block (NMB), allowing for a controlled and prompt recovery. To guide the NMB, a monitoring modality (acceleromyography) was used to measure the depth of the NMB and ensure precise timing of drug administration. This technique has not been described in marine mammals yet. The sea lion recovered without complications. This report explores the potential of applying established yet still evolving veterinary techniques—such as acceleromyography and the use of sugammadex—to enhance anesthesia safety and recovery in pinnipeds, thereby improving their overall welfare during medical procedures.

Abstract

Neuromuscular blocking agents (NMBAs) are essential in intraocular surgeries to improve surgical conditions and ensure optimal ventilation. However, residual blockade can pose significant risks, particularly in pinnipeds due to their unique diving physiology. This case report examines the use of sugammadex for reversing the effect of rocuronium and the application of acceleromyography (AMG) for monitoring of neuromuscular block (NMB) in a California sea lion undergoing lensectomy. Rocuronium (0.3 mg/kg IV) was used to achieve complete NMB, and an additional 0.1 mg/kg to prolong the block. Sugammadex (1 mg/kg IV) effectively reversed the NMB within 90 seconds. Neuromuscular function was monitored using AMG, with the ulnar nerve in the front flipper serving as the stimulation site. The AMG allowed for objective monitoring of neuromuscular blockade, ensuring accurate titration of the NMBA and its reversal agent. This case represents the first report describing the use of sugammadex in a sea lion for reversing the effect of rocuronium and the use of AMG for monitoring of NMB, demonstrating its potential for improving anaesthesia protocols and patient safety in marine mammal anaesthesia.

Keywords: cataracts; marine mammal anesthesia; neuromuscular monitoring; pinnipeds; reversal of neuromuscular blockade; train-of-four

1. Introduction

A significant proportion of captive pinnipeds, including California sea lions (Zalophus californianus), suffer from ocular conditions such as corneal disease, premature cataracts, and lens luxations [1,2]. These conditions often necessitate surgical intervention, which requires precise eye positioning and complete immobility, as even minor movements can compromise surgical outcomes. Neuromuscular blocking agents (NMBAs) are therefore critical in marine mammal ophthalmic

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surgery to facilitate central eye position, optimize surgical conditions, reduce intraocular pressure, and improve ventilation control [1–6].

Rocuronium, a non-depolarising NMBA, is commonly used in veterinary anesthesia due to its rapid onset, intermediate duration, and favorable cardiovascular profile [7–11]. However, the risk of residual neuromuscular blockade (NMB) poses a significant concern, especially in pinnipeds whose unique respiratory physiology—including voluntary apnea and a pronounced diving reflex—requires a smooth, quick and complete recovery from anesthesia [12,13]. Sugammadex, a modified γ-cyclodextrin, provides rapid and predictable reversal of rocuronium-induced blockade without the need for anticholinergics in small and large animals (14-16). Its ability to prevent residual paralysis makes it particularly valuable in high-risk species [17–19].

Monitoring neuromuscular function is essential for the safe and effective use of NMBAs and their reversal agents. Acceleromyography (AMG) offers an objective (quantitative), real-time method of neuromuscular monitoring by measuring the acceleration of muscle contractions in response to peripheral nerve stimulation. This technique provides greater precision and objectivity compared to traditional subjective visual or tactile methods. In veterinary medicine, AMG has been successfully used in dogs, cats and horses to guide NMBA dosing and assess recovery [17,18,20]. Despite its utility, the use of AMG has not previously been reported in pinniped species. One of the stimulation sites is the ulnar nerve which arises from the brachial plexus in pinnipeds, formed by the sixth cervical to the first thoracic spinal nerves [21]. It runs along the medial aspect of the forelimb, passing posterior to the olecranon process, and provides motor and sensory innervation to the musculature and soft tissues [22,23]. Due to the paddle-like structure of pinniped fore flippers, the ulnar nerve remains deep, but can be accessed near the ulnar nerve groove, just medial to the olecranon making it suitable for nerve stimulation and neuromuscular monitoring [21].

This case report presents the first documented use of sugammadex for reversing rocuronium in a California sea lion, along with the novel application of acceleromyography for intraoperative neuromuscular monitoring. The aim is to demonstrate how these tools can enhance anaesthetic safety and improve perioperative outcomes in marine mammal surgical care.

2. Case Presentation

2.1. Medical History

A 19-year-old male California sea lion (Zalophus californianus), weighing 187 kg, with bilateral hyper mature cataracts was scheduled for ophthalmic surgery. One week prior to surgery, topical ophthalmic treatment was initiated to optimize ocular conditions for the procedure. The regimen included tri-antibiotic drops containing gramicidin, neomycin sulfate, and polymyxin B sulfate (Oftalmowell®, Teofarma S.R.L.), administered as one drop three times daily (TID) in both eyes (OU); ciprofloxacin 3 mg/mL (Oftacilox®, NTC S.R.L.), one drop TID OU; prednisolone 10 mg/mL (Pred Forte®, AbbVie Spain, S.L.U.), one drop TID OU; and nepafenac 3 mg/mL (Nevanac®, Novartis Europharm Limited), one drop twice daily (BID) OU.

Systemic preoperative treatment, initiated 72 hours before the procedure, consisted of oral gabapentin (Gabapentina, Kern Pharma, Spain) at 800 mg BID, prednisone (Prednisona Cinfa, Laboratorios Cinfa, Spain) at 75 mg once daily, and famotidine (Famotidina Cinfa, Laboratorios Cinfa, Spain) at 80 mg BID. Blood work performed under anesthesia revealed values within normal limits.

2.2. Anesthesia Protocol

The animal was premedicated with midazolam (Midazolam Normon, Normon, Spain) (0.2 mg/kg IM), butorphanol (Butomidor, Richter Pharma, Austria) (0.2 mg/kg IM), medetomidine (Domtor, Ecuphar, Spain) (0.01 mg/kg IM), and ketamine (Ketamidor, VetViva Richter, Austria) (1 mg/kg IM). No additional induction agents were necessary for endotracheal intubation using a 18 Fr endotracheal tube (Surgivet, USA). Anaesthesia was maintained using isoflurane (Isoflutek,

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Laboratorios Karizoo, Spain) in oxygen delivered via a circle system MDS Matrx VML Anesthesia Machine (MDS Inc., USA). Hypothermia prevention was ensured using two thermal blankets (Cecotec, Spain), one placed on top and one underneath the animal.

Monitoring consisted of side stream capnography, pulse oximetry (SpO_2 probe placed on the tongue), electrocardiography (heart rate and arrhythmia analysis), and non-invasive blood pressure measurement, using a multi parameter monitor (Mindray PM 9000 Vet, USA). Internal body temperature was measured rectally (BioTex Temp Loop, BOSCOGEN, USA). Inspired and expired concentrations of oxygen and isoflurane were measured using a multi gas analyzer (Vamos, Dräger, Germany). All data were manually recorded every 5 minutes. Cefazolin (22 mg/kg, Cefazolina Normon, Spain) was administered intravenously (IV) 20 minutes before the start of surgery. Additionally, a saline infusion (Fisiovet, Braun, Spain) was administered IV throughout the procedure at a rate of 5 mL/kg/h.

2.3. Nerve Stimulation, Neuromuscular Blocking and Monitoring

For neuromuscular blockade monitoring, the ulnar nerve was selected for stimulation using a train-of-four (TOF) stimulation pattern (Stimpod, Xavant, Australia). The sea lion was positioned in lateral recumbency with the fore flipper extended and supported to allow free movement of the limb. A transcutaneous electrical nerve mapping probe (Stimpod, Xavant, Australia) was used to locate the optimal stimulation site. The probe was applied firmly to the skin at the medial aspect of the fore flipper, near the olecranon process, and moved slowly along the inner surface of the fore flipper. The position where the current of 20 mA with stimulation of 5Hz induced maximal movement of the flipper was identified. Once the optimal position for the stimulation of the ulnar nerve was located, the stimulating electrode using a stainless steel luer-lock needle was placed through the skin at this precise site.-The zero electrode was placed two centimeters proximal to the stimulation electrode on the dorsolateral surface of the antebrachial region. (Figure 1.)

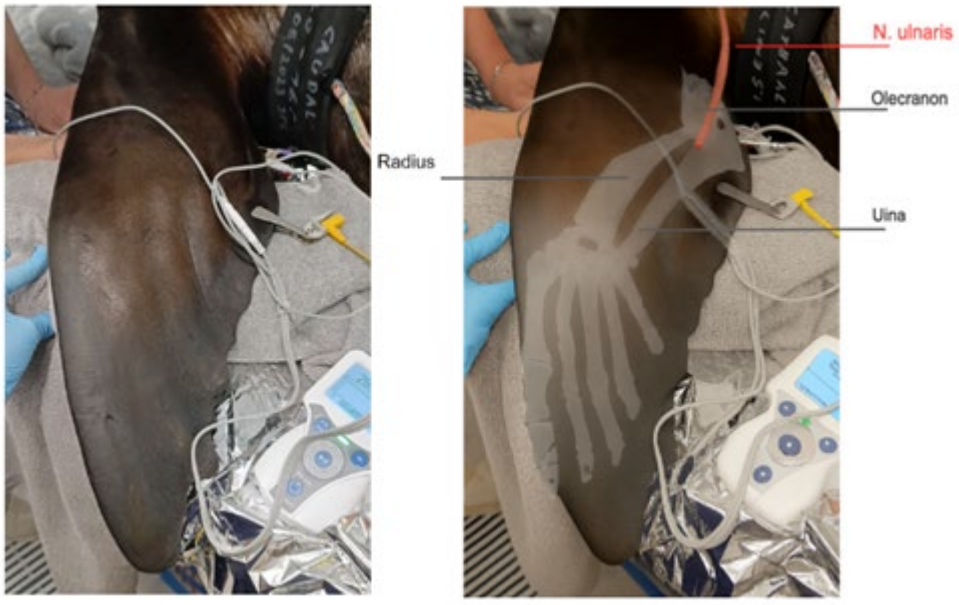

Figure 1. Anatomical landmarks and electrode positioning for ulnar nerve stimulation in the foreflipper of a California sea lion.

For AMG, the transducer was positioned on the dorsal side of the fore flipper, caudally, at the site of maximal movement (Figure 2.). The AMG transducer was secured with a tape, and a TOF stimulation pattern was employed, with supramaximal stimulation set at 50 mA and a frequency of

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2 Hz, delivering 2-second duration pulses every 15 seconds. This allowed for continuous monitoring of NMB and ensured accurate assessment of muscle response during anaesthesia.

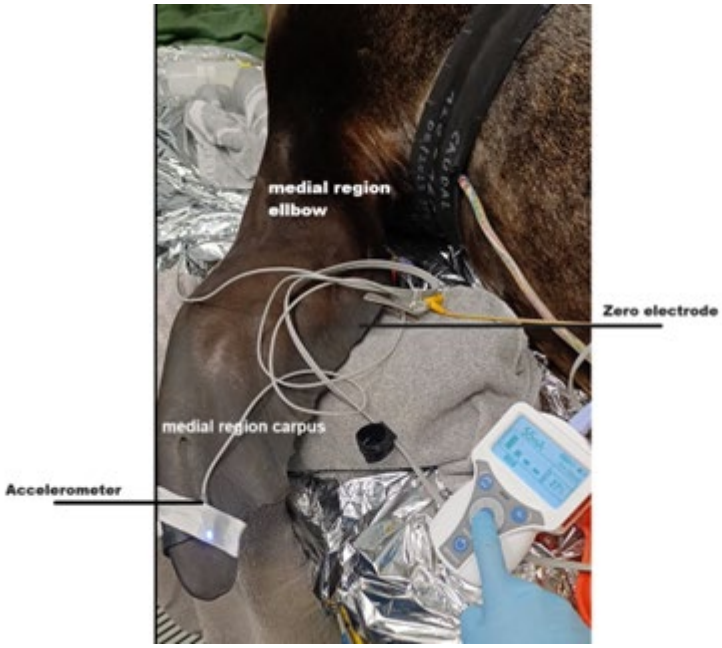

Figure 2. Placement of Acceleromyography (AMG) Transducer for Neuromuscular Monitoring in the Fore Flipper of a California Sea Lion.

The monitoring was continued for a period of 10 minutes to allow stabilization of the recordings before the administration of the NMBA.

Deep NMB was achieved using rocuronium (Rocuronium Kabi, Fresenius Kabi, Germany) at a dose of 0.3 mg/kg IV for surgery of the first eye. Complete blockade (TOF count 0/4) was reached within 4 minutes. The first twitch returned 47 minutes after administration, followed by the second twitch at 51 minutes. Because the surgeon did not report any changes in eye position, a second dose of rocuronium (0.1 mg/kg IV) was administered only 83 minutes after the initial dose for the surgery on the second eye, when the TOF ratio was 31% and TOF count 4/4. Two minutes after the second dose, the TOF ratio was 35% with a TOF count of 4/4. After another 28 s, the TOF count decreased to 1 /4 and remained at that level until deep NMB was achieved. Complete NMB, with no visible twitches, was achieved at 4 minutes and 48 seconds after re-dosing. The first twitch returned 37 minutes after the second dose, the second at 46 minutes. After 48 min a TOF ratio of 9% was visible. Sugammadex (Sugammadex, Fresenius Kabi, Germany) was administered at a dose of 1 mg/kg IV, 53 minutes after the second rocuronium dose, still at a TOF ratio of 9%. TOF ratio increased to 1.15 within 1 minute and 30 seconds after sugammadex administration and reached 0.9 at 54 seconds. No signs of recurarisation were observed for the following 3 minutes after which NMB monitoring was stopped.

2.4. Recovery and Postoperative Management

Recovery was smooth, with extubation performed 20 minutes after cessation of isoflurane. The animal was closely monitored during recovery, with administration of reversal drugs: atipamezole (Antisedan, Ecuphar, Belgium) (0.075 mg/kg IM), flumazenil (Flumazenil, B. Braun, Germany) (0.015 mg/kg IM), and naloxone (Naloxona, Kern Pharma, Spain) (0.01 mg/kg IM). Other postoperative medications included dexamethasone (Dexadreson, MSD Animal Health, Netherlands) (0.16 mg/kg IM), cefovecin (Convenia, Zoetis, USA) (4 mg/kg SQ), enrofloxacin (Baytril, Elanco, USA) (5 mg/kg SQ), and others as outlined.

Follow-up at five days postoperatively indicated satisfactory healing with no complications.

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3. Discussion

This case provides the first documented evidence that AMG and sugammadex can be successfully applied in a California sea lion undergoing ophthalmic surgery to manage and reverse NMB. AMG was not only technically feasible in this pinniped but also clinically beneficial for optimizing both the depth and timing of NMB use and reversal.

Despite anatomical challenges—such as the modified forelimb structure and the deep location of the ulnar nerve—a transcutaneous nerve mapping probe enabled accurate identification of the stimulation site (21, 22). Once positioned, the AMG transducer reliably recorded TOF responses throughout anaesthesia, demonstrating that neuromuscular monitoring techniques commonly used in terrestrial species can be successfully adapted to marine mammals.

Moreover, the use of AMG allowed individualized titration of rocuronium, confirming deep NMB (TOF 0/4) within 4 minutes after a 0.3 mg/kg IV dose, which is a longer onset time but lower dose to achieve deep block than described for other land mammals, where the onset is 98 ± 52 seconds with 0.4 mg/kg IV in dogs, 46 ± 11 seconds with 0.6 mg/kg IV in cats, and 2.3 ± 2 minutes with 0.3 mg/kg IV in horses (24-26) It also revealed a recovery pattern that differed from domestic species. The return of the first twitch occurred 47 minutes after the initial 0.3 mg/kg IV dose and 48 minutes after a supplemental 0.1 mg/kg dose, despite a relatively low cumulative dose. In contrast, 0.3 mg/kg rocuronium typically results in a block duration of 20–35 minutes in dogs and horses, and 10–15 minutes in cats (24–26). Interestingly, a transient increase in TOF ratio from 31% to 35% was observed two minutes after the second rocuronium dose, despite the expected progression of neuromuscular block. This was followed by a gradual decrease in TOF count over the next several minutes, with complete NMB achieved only after 4 minutes and 48 seconds. The sea lion's prolonged and delayed response to rocuronium suggests that pinnipeds may metabolize the drug more slowly due to species-specific hepatic clearance, reduced protein binding, or slower elimination (27). These findings underscore the importance of objective quantitative neuromuscular monitoring to ensure both optimal surgical conditions (onset and depth of block) and safe recovery from NMB.

Furthermore, AMG proved instrumental not only for ensuring adequate blockade during surgery but also for guiding the recovery phase. It verified complete NMB intraoperatively and enabled real-time monitoring of twitch return and TOF ratio during recovery, allowing precise dosing of the reversal agent. This individualized feedback was critical in a species lacking validated monitoring standards and highlights again AMG's safety and utility in pinnipeds. By detecting a TOF ratio of only 9% at 53 minutes after the second dose, AMG enabled timely and precise reversal. Without such monitoring, residual blockade could have gone undetected, increasing the risk of hypoventilation, apnea, or respiratory compromise—especially in diving species with voluntary apnea and a strong diving reflex (28–31).

Importantly, AMG also guided the decision to administer a reduced dose of sugammadex (1 mg/kg), rather than the standard 2–4 mg/kg recommended in dogs and humans for moderate to deep block. This individualized titration, based on neuromuscular function rather than fixed dosing, not only ensured safety and efficacy but also minimized drug use. Considering the high cost of sugammadex, this approach may be particularly relevant in veterinary settings where financial constraints often limit access to advanced pharmaceuticals. Thus, AMG contributed not only to clinical safety but also to cost-effective anesthetic management.

The use of sugammadex for reversing rocuronium-induced blockade has been well documented in veterinary species. Reported doses range from 0.5 mg/kg in horses to 4–5.5 mg/kg in dogs and ponies, with reversal typically occurring within 2–4 minutes (32-34). Our case demonstrates that even a relatively low dose (1 mg/kg) can provide complete and predictable reversal in pinnipeds. This supports the feasibility and potential cost-effectiveness of a low-dose regimen in pinnipeds. Furthermore, rapid recovery minimized the risks associated with extubation. Traditional reversal agents like neostigmine are less reliable and require anticholinergic co-administration, which may cause cardiovascular and secretory side effects (36). Sugammadex directly encapsulates rocuronium

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and has demonstrated superior efficacy and safety in dogs, horses, and ponies (32-35, 37, 38). Our findings suggest that these benefits may extend to pinnipeds as well.

Despite the positive outcome, this case highlights important limitations. There are no species-specific reference values for TOF ratios that indicate adequate spontaneous ventilation in marine mammals, nor standardized guidelines for electrode placement in pinnipeds. This lack of standardization for use of NMB monitoring complicates interpretation and raises ethical concerns, as clinicians must rely on extrapolated data from land mammals.

Although sugammadex was effective at 1 mg/kg in this case, pharmacokinetic and pharmacodynamic studies are needed to define optimal dosing in pinnipeds. This is especially important in animals with hepatic or renal impairment, given interspecies metabolic variability and the liver-based clearance of rocuronium (39). Furthermore, due to the high cost of sugammadex, evidence-based, cost-efficient protocols are essential. **While no signs of recurarization were observed, the monitoring period was short, which represents a limitation. However, no clinical signs of recurarization were noted during the observation period.**

Future research should aim to establish AMG reference values and electrode positioning guidelines in marine mammals, and to characterize species-specific pharmacokinetics of rocuronium and sugammadex. Finally, developing ethical and clinical standards for NMB monitoring in pinnipeds will be essential to ensure safe and effective anaesthesia.

4. Conclusions

This case demonstrates the successful and safe use of AMG and sugammadex in a California sea lion undergoing lensectomy, marking their first documented application in a pinniped species. AMG enabled real-time, objective neuromuscular monitoring, which facilitated precise titration of rocuronium and guided the optimal dosing of the reversal agent. Sugammadex provided a rapid, complete, and complication-free recovery from neuromuscular blockade without any signs of recurarisation. These findings support the feasibility and potential benefits of incorporating these techniques into marine mammal anaesthetic protocols, while also highlighting the urgent need for species-specific reference data and standardised guidelines to optimize their application in this unique group of patients.

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Abbreviations

The following abbreviations are used in this manuscript:

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Acceleromyography	AMG
Bis in die, twice a day	BID
Intramuscular	IM
Intravenous	IV
Neuromuscular Block	NMB
Neuromuscular Blocking Agent	NMBA
Oculus uterque, both eyes	OU
Subcutaneous	SQ
Train-of-Four	TOF

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