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SHORT COMMUNICATION

Field immobilisation of adult Weddell seals using intramuscular butorphanol and midazolam

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Abstract

Background: When working with free-ranging phocid seals, methods of chemical immobilisation require ongoing refinement to reduce complications, particularly apnoea, during research procedures.

Methods: Adult Weddell seals (n = 20) at Cape Crozier, Antarctica, were chemically immobilised with intramuscular injection of butorphanol and midazolam in 2024 and 2025.

Results: Butorphanol and midazolam were administered intramuscularly at 0.16 ± 0.03 and 0.19 ± 0.03 mg/kg, respectively. No apnoea lasting more than 2 minutes was observed, nor were any other adverse effects.

Limitations: The sample was limited to 20 adults, predominantly mid-lactation females (n = 14). Additional data on other demographic groups, varying the dose combination, more detailed records of seal vital signs, and additional physiological measurements (e.g., blood gases) would provide valuable insight into this drug combination for Weddell seals.

Conclusion: In this limited study, intramuscular butorphanol and midazolam were a safe and effective combination for field immobilisation of adult Weddell seals.

INTRODUCTION

Refining animal capture and handling methods is an integral part of wildlife research. Attaching biologging devices (hereafter 'biologgers') to free-ranging animals is a growing area of research, but requires safely capturing animals with minimal physiological or behavioural side effects.[1–4] Marine mammals can be particularly challenging to chemically immobilise due to their specialised physiology adapted for diving (i.e., profound bradycardia, peripheral vasoconstriction, apnoea and voluntary respiration).[5–7] Consequently, prolonged apnoea is a common complication encountered during chemical immobilisation of phocid seals that researchers strive to mitigate and minimise.[7,8]

Weddell seals (*Leptonychotes weddellii*) are an extensively studied Antarctic phocid[9–12]; however, they can be challenging to immobilise safely, even using agents commonly used in other Southern Ocean phocid species.[13] The most common agents used in Weddell seals include non-reversible injectables (i.e., tiletamine or ketamine combined with a benzodiazepine) or a combination of injectable sedatives and inhalant agents (i.e., isoflurane or sevoflurane).[13–17] Recently, researchers have started using butorphanol combined with midazolam in phocid species, including adult leopard seals (*Hydrurga leptonyx*),[18] Weddell seal pups[19] and harbour seal (*Phoca vitulina*) pups,[20] with promising results as a safe, reversible method of immobilisation for this group of animals. However, more documentation of this method across species and age classes is needed to provide guidance to practitioners in the field.

MATERIALS AND METHODS

Animal handling was processed under National Marine Fisheries Service permit #25770, Antarctic Conservation Act permit #2025-010, and with oversight and approval of the UC Santa Cruz Institutional Animal Care and Use Committee (Holsr2407) and the University of Canterbury Animal Ethics Committee (AEC2024/03R).

Animal captures took place at Cape Crozier (77.4576°S, 169.2637°E) in Antarctica during November 2024 and 2025. Each year, 10 animals were selected for handling and biologger attachment based on their condition (e.g., healthy, no large open wounds, normal behaviour) and our ability to access them safely on the sea ice. Animals were captured using a pinniped capture net and given an intramuscular (IM) injection of butorphanol and midazolam, administered either into the lower pelvic limb (*gastrocnemius)* using a 1.5" 18 Ga needle (2024 procedures) or the lumbar abdominal muscles using a 3.5" 18 Ga spinal needle (2025 procedures). IM injections were usually administered at a single site. In 2025, we administered a standard initial injection to all animals (6 mL of 5 mg/mL butorphanol and 14 mL of 5 mg/mL midazolam); this was a slight reduction in butorphanol and an increase in midazolam compared to 2024 doses (see Table 1). To help facilitate induction, we covered the animals' eyes with a towel once they were moderately sedated. If another dose was needed to achieve adequate immobilisation, additional drugs were administered intravenously (IV) through the extradural vein via a "3.5–6" 18 Ga spinal needle.

Animal vital signs (i.e., heart rate [HR], respiration rate [RR], capillary refill time [CRT] and mucus membrane colour) and immobilisation depth were monitored during procedures. Immobilisation depth was assessed on a scale from 0 to 8 (described earlier[21]). Our target immobilisation depth was 4–5 (light to heavy immobilisation) to allow attachment of biologgers to the top of the head. When handling was complete, we administered 0.7–1.4 mL of 50 mg/mL naltrexone IV (median 0.175 mg/kg, range: 0.099–0.242 mg/kg), an opioid receptor antagonist, to reverse the sedative effect of butorphanol. In two cases, we also partially reversed the sedative effect of midazolam using 10.0 or 11.0 mL of 0.1 mg/mL flumazenil, a GABA receptor inverse agonist (0.0023 and 0.0045 mg/kg, respectively). Animals were observed to ensure a good recovery, including a successful reunification with their pup for lactating females. We calculated an estimated mass from morphometric measurements using the commonly used equation validated by Castellini and Kooyman.[22] We report time in minutes for induction (IM injection to immobilisation depth of 4), procedure duration (IM injection to reversal injection), and recovery (reversal injection to animal ambulatory) for each handling (Table 1). All results are presented as mean ± SD. Figures were prepared using R version 4.3.2.[23]

RESULTS

We successfully immobilised 20 Weddell seals (14 lactating females, three non-reproductive females and three males) using butorphanol and midazolam administered IM with IV augmentation as needed. Immobilisations using lumbar abdominal IM injection (all 2025 procedures, n = 10) provided more reliable and consistent inductions with less need for IV augmentation compared to IM injection into the lower pelvic limb (Table 1). In 2024, the initial dose used was 0.17 ± 0.04 mg/kg butorphanol and 0.16 ± 0.03 mg/kg midazolam. Augmentation was required in eight of 10 procedures, and the mean total augmentation dose was 0.08 ± 0.03 mg/kg butorphanol and 0.07 ± 0.03 mg/kg midazolam (Table 1). In 2025, initial doses were 0.16 ± 0.03 mg/kg butorphanol and 0.19 ± 0.03 mg/kg midazolam. Only four animals, including the three largest individuals, required augmentation totalling 0.015 ± 0.01 mg/kg (range: 0.01–0.02 mg/kg) of both butorphanol and midazolam (Table 1, Figure 1). All animals (2024 and 2025) achieved an immobilisation depth ≥4; however, depths were not consistently recorded during 2024 procedures. The deepest recorded immobilisation was a 6 (light anaesthesia), observed in a non-reproductive female 2025 (WS25-07; Figure 1). Reversal of butorphanol was effective, with full recovery (ambulatory) 2 minutes following IV injection of naltrexone (Table 1).

Animals responded well to the immobilisations, and there were no instances of apnoea greater than 2 minutes, nor were there any adverse effects observed. All animals maintained pink mucous membranes with CRT less than 2 seconds. We recorded RR an average of three times (range: 1–6) per procedure in n = 7 procedures in 2024 and three times (range: 1–5) in n = 10 procedures in 2025. During 2024 procedures, RR was 10 ± 3 breaths per minute, and during 2025 procedures, it was 8 ± 3 breaths per minute. We did not record HR in 2024. In 2025, we recorded HR two times (range: 1–4) in n = 7 animals. The mean recorded HR across all animals was 60 ± 11 beats per minute, ranging from 46 to 78 beats per minute. Moreover, in 2025, we opportunistically observed (via flipper tags, a uniquely identifying mark) that five of the seals handled in 2024 at Cape Crozier were healthy.

DISCUSSION

While our sample size was limited to 20 individuals, predominantly mid-lactation females (n = 14), we found the combination of butorphanol and midazolam to be an effective and safe method of immobilisation in healthy adult Weddell seals, similar to previous work on Weddell seal pups.[19] We had no instances of apnoea exceeding 2 minutes, nor was cyanosis observed. Initial injections via the lumbar-abdominal region with longer needles were more reliable, likely due to the greater ease of administering the injection completely if animals moved and to the increased likelihood that injections were delivered into the muscle rather than into the blubber. Variation in pre-injection handling stress

TABLE 1 Summary procedure information for 20 Weddell seals immobilised in 2024 and 2025.

Seal ID	Sex	Calculated mass (kg)	Initial dose Butorphanol/ Midazolam (mg/kg)	Additional dose Butorphanol/ Midazolam (mg/kg)	Induction time (minutes)	Procedure duration (minutes)	Recovery time (minutes)
WS24-01	F	352	0.10/0.10	0.09/0.04	34	69	2
WS24-02	M	242	0.21/0.21	0.10/0.05	33	67	2
WS24-03	F	433	0.16/0.15	0.12/0.12	28	66	1
WS24-04	F	309	0.23/0.21	0.02/0.02	22	44	3
WS24-05	F	355	0.20/0.18	–	14	39	3
WS24-06	F	370	0.19/0.18	0.10/0.10	14	42	2
WS24-07	F	428	0.16/0.15	0.09/0.09	30	59	3
WS24-08	F	439	0.16/0.15	0.05/0.05	13	44	2
WS24-09	F	461	0.15/0.14	0.11/0.11	19	41	2
WS24-10	F	534	0.13/0.12	0.06/0.06	15	39	3
2024 Mean:		392 ± 80	0.17 ± 0.04 /0.16 ± 0.03	0.08 ± 0.03 /0.07 ± 0.03	22.2 ± 8.0	51.0 ± 12.0	2.3 ± 0.6
2024 Median (range)		399 (242–534)	0.16 (0.10–0.23)/0.15 (0.10–0.21)	0.09 (0.02–0.12)/0.06 (0.02–0.12)	20.5 (13–34)	43 (39–69)	2 (1–3)
WS25-01	F	341	0.18/0.21	–	15	46	3
WS25-02	F	316	0.19/0.22	–	15	47	2
WS25-03	M	411	0.15/0.17	0.02/0.02	19	47	2
WS25-04	F	328	0.18/0.21	–	12	38	3
WS25-05	F	289	0.21/0.24	–	14	42	1
WS25-06	F	505	0.12/0.14	0.01/0.01	19	49	2
WS25-07	F	340	0.18/0.21	0.01/0.01	20	40	2
WS25-08	M	524	0.11/0.13	0.02/0.02	24	49	2
WS25-09	F	401	0.15/0.17	–	13	34	2
WS25-10	F	328	0.18/0.21	–	21	45	2
2025 Mean:		378 ± 77	0.16 ± 0.03 /0.19 ± 0.03	0.02 ± 0.01 /0.02 ± 0.01	17.2 ± 3.7	43.7 ± 4.8	2.1 ± 0.5
2025 Median (range)		340.5 (289–240)	0.18 (0.11–0.21)/0.21 (0.13–0.24)	0.015 (0.01–0.02)/0.015 (0.01–0.02)	17 (12–24)	46.5 (34–49)	2 (1–3)

Note: Means are accompanied by standard deviation. In 2024, all injections were administered IM to the lower pelvic limb, whereas in 2025, all injections were administered intramuscularly (IM) to the lumbar abdominal region. Induction time is minutes from IM injection to immobilisation depth of 4. Procedure duration is minutes from IM injection to reversal injection. Recovery time is minutes from reversal injection to the animal being ambulatory.

(i.e., number of attempts needed to restrain the animal, duration of restraint) and stimulation during induction (i.e., pup calling) also likely contributed to differences in induction outcomes between individuals, although we did not quantify these factors. Minimising stress and stimulation before and during induction should always be the goal to optimise the overall immobilisation.

We used low-concentration formulations of both substances and limited the total volume of single-site injections to 20 mL. However, using higher concentrations of both drugs would enable quicker, easier initial injections, likely eliminating the need for physical restraint, and would further reduce animal stress before chemical immobilisation. Higher concentrations would also enable us to administer more appropriate IM doses to larger animals while keeping injection volumes reasonable. Unfortunately, delivery of controlled substances to the Antarctic was difficult, restricting us to using low-concentration substances. Regardless, we recommend that future work plan for multiple IM injection sites if they are administering volumes greater than 12 mL, as described before,[17] to minimise the risk of localised tissue damage, pain or infection. While we did not observe indications of negative effects in the days following immobilisation (no swelling, draining tracks, etc.), this risk can be reduced by using multiple IM sites.

The fully reversible nature of this drug combination is a valuable added margin of safety, especially in field settings where other intervention capabilities can be limited. We found that animals rapidly regained awareness and mobility following naltrexone administration. Lactating females recovered particularly consistently, quickly moving back to their pups, vocalising and interacting with them within 2–3 minutes.

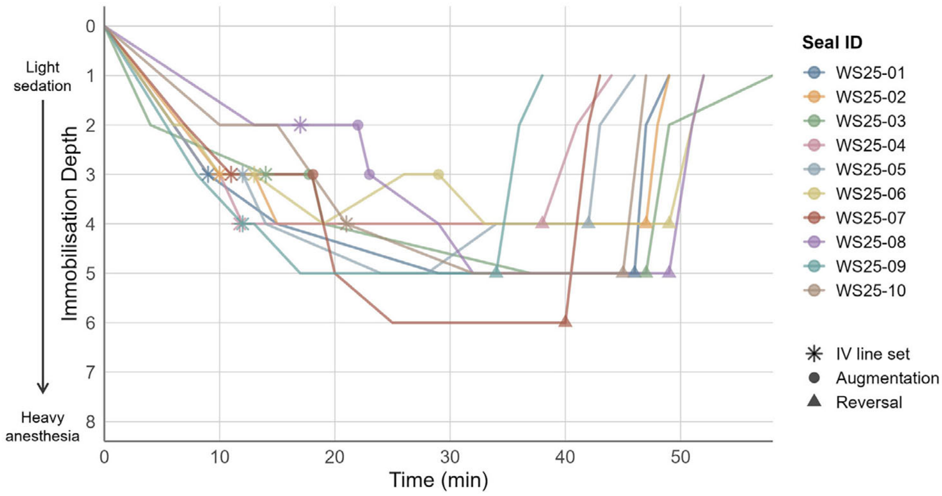

FIGURE 1 Immobilisation depth across procedures for 10 Weddell seals handled at Cape Crozier, Antarctica in 2025. The initial injection was administered at Time = 0. A depth of 0 represents normal behaviour, 1–3 is light to heavy sedation, 4–5 is light to heavy immobilisation, and 6–8 is light to heavy anaesthesia.[21] The sedative effect of midazolam was not reversed in any animals, so recovery depth was scored as 1. WS25-03 and WS25-08 were male, WS25-07 was a non-reproductive female, and all others were lactating females.

One animal with a slower recovery was a male. It regained head movement quickly but was slower to move its whole body and appeared drowsy. During the 2024 season, we administered both naltrexone and flumazenil to one male and one lactating female. Compared to animals that only received naltrexone, the female recovered similarly, but the male exhibited a more abrupt recovery—it became highly mobile almost immediately and very rapidly moved away from the procedure site into the water. Reversing the sedative effects of butorphanol alone was sufficient in all other animals, and recoveries were smooth and calm.

Further investigation is required to understand the effectiveness of this drug combination on more diverse age, sex and life history stages. Moreover, testing variations of the dose combination while recording more detailed and regular vital signs and additional physiological measurements (e.g., blood gases) would provide valuable insight into the efficacy of this method for Weddell seals. Based on our experience, the combination of butorphanol and midazolam is an effective and safe immobilisation method for Weddell seals that provides a consistent alternative to existing methods, with the added benefit of being reversible.

AUTHOR CONTRIBUTIONS

Rachel R. Holser: Conceptualisation (lead), data curation (lead), investigation (equal), project administration (supporting), writing—original draft (lead), writing—review and editing (equal). **Rachel P. Hickcox**: Conceptualisation (supporting), data curation, investigation, writing—review and editing (equal). **Daniel P. Costa**: Investigation (equal), funding acquisition (supporting), project administration (supporting), writing—review and editing (equal). **Thomas Hildebrand**: Investigation (equal), writing—review and editing (equal). **Sarah P. Flanagan**: Investigation (equal), writing—review and editing (equal). **Michelle A. LaRue**: Funding acquisition (lead), investigation (equal), project administration (lead), writing—review and editing (equal).

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

Animal handling was processed under National Marine Fisheries Service permit #25770, Antarctic Conservation Act permit #2025-010, and with oversight and approval of the UC Santa Cruz Institutional Animal Care and Use Committee (Holsr2407) and the University of Canterbury Animal Ethics Committee (AEC2024/03R).

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