DOI: 10.1002/vms3.1001

CASE REPORT

WILEY

Fentanyl-induced muscle rigidity in a dog during weaning from mechanical ventilation after emergency abdominal surgery: A case report

Kazumasu Sasaki[1,2,3] | Roberto Rabozzi[4] | Shinya Kasai[3] | Kazutaka Ikeda[3] | Tatsuya Ishikawa[2]

[1]Small Animal Emergency and Critical Care Service, Sendai Animal Care and Research Center, Sendai, Japan

[2]Research Institute for Brain and Blood Vessels, Akita Cerebrospinal and Cardiovascular Center, Akita, Japan

[3]Addictive Substance Project, Tokyo Metropolitan Institute of Medical Science, Tokyo, Japan

[4]CVRS-Policlinico Veterinario Roma Sud, Rome, Italy

Correspondence
Kazumasu Sasaki, Small Animal Emergency and Critical Care Service, Sendai Animal Care and Research Center, Sendai, Japan.
Email: k-sasaki@gaea.ocn.ne.jp

Funding information
The Sendai Animal Care and Research Center Foundation; Intramural foundation of the Research Institute for Brain and Blood Vessels, Akita Cerebrospinal and Cardiovascular Center (21-01)

Abstract

A 22.5-kg, 8.4-year-old female mixed breed dog was presented for an emergency ovariohysterectomy for pyometra. No neurological abnormalities were observed on preoperative physical examination. Surgery was completed uneventfully under fentanyl- and sevoflurane-based anaesthesia. Cardiorespiratory indices remained stable under mechanical ventilation throughout the procedure. Approximately 23 min after the discontinuation of fentanyl infusion, the investigator noticed jaw closure and stiffness and thoraco-abdominal muscle rigidity. To rule out fentanyl-induced muscle rigidity, naloxone was administered. Following administration of naloxone, there was a return of spontaneous respiratory effort, indicated by capnogram and visible chest wall excursion. Based on the clinical signs and response to naloxone administration, the dog was diagnosed with suspected fentanyl-induced muscle rigidity. Six minutes after the return of spontaneous respiration, the dog was extubated uneventfully without additional naloxone administration. During 4 days of postoperative hospitalization, no recurrent muscle rigidity was observed, and the patient was discharged safely. The total dose of fentanyl administered was 0.61 mg (27 μg kg^{-1}).

KEYWORDS
case report, dog, fentanyl, muscle rigidity, opioid, perioperative period

1 | INTRODUCTION

Although the underlying mechanism has not yet been defined, opioid-induced muscle rigidity is well recognized in humans during the perioperative period and during intensive care unit (ICU) admission (Dewhirst et al., 2012; Ming & Singh, 2019; Roy & Fortier, 2003; Trujillo et al., 2020). In humans, it has been reported that fentanyl and other opioids impair skeletal muscle function and cause various symptoms, including generalized muscle stiffness, jaw clenching, truncal rigidity, neck and masseter muscle spasm, laryngospasm, limb flexion and extension, and neurological signs (Fahnenstich et al., 2000; Roan et al., 2018). In preclinical settings, specific strains of rats (Lai & Lui, 2000; Weinger et al., 1995), rabbits (Soares et al., 2014), and guinea pigs (Brent & Bot, 1992) developed opioid-induced muscle rigidity and were considered potential translational animal models in relevant research fields. Furthermore, this phenomenon has been reported in other animal species as well, including equids (Knych et al., 2015) and elk (Paterson et al., 2009). Here, we describe the rare case of a

client-owned dog with jaw stiffness and truncal rigidity during recovery from fentanyl- and sevoflurane-based general anaesthesia for emergency abdominal surgery.

2 | CASE HISTORY

A 22.5-kg, 8.4-year-old female mixed breed dog was presented for an emergency ovariohysterectomy for pyometra. Preoperative physical examination revealed that the blood microfilaria and *Dirofilarial* antigen tests were positive (CHW Ag test kit; Kyokuto Pharmaceutical Industrial Co., Ltd., Tokyo, Japan) and that the leukocyte count was elevated; however, other laboratory data, including complete blood count, biochemical values, and coagulation profiles such as prothrombin time, activated partial thromboplastin time, and fibrinogen levels revealed no abnormalities. A diagnosis of pyometra was made based on the dog's medical history, namely the recent heat cycle, clinical signs including anorexia, polyuria/polydipsia, the elevated leukocyte count, and abdominal ultrasound results. No neurological abnormalities were observed on visual examination. Furthermore, the dog had no known history of psychostimulant administration, including opioids. The patient's owner provided informed written consent for emergency surgery and publication of this report.

The dog was premedicated with intravenous (IV) fentanyl (10 μg kg^{-1}; Fentanyl; Daiichi Sankyo Propharma Co., Ltd., Tokyo, Japan), and general anaesthesia was induced with IV propofol (Propofol; Maruishi Pharmaceutical Co., Ltd., Osaka, Japan) administered to effect. After uneventful endotracheal intubation, epidural 0.5% bupivacaine (0.3 ml kg^{-1}; Marcain Injection 0.125% 0.25% 0.5%; Sandoz, Tokyo, Japan) was administered at the lumbar–sacral (L7–S1) intervertebral space with an 18-gauge, 80-mm Tuohy needle (Hakko Disposable Epidural Needle; Hakko Co., Ltd., Nagano, Japan). Anaesthesia was maintained with a continuous rate infusion (CRI) of fentanyl (0.2–0.4 μg kg^{-1} min^{-1}) and end-tidal concentration of 3–3.5% of sevoflurane (Sevofrane; Maruishi Pharmaceutical Co., Ltd., Osaka, Japan), with fraction of inspired oxygen (FiO_2) of 0.6 (fresh gas flow 2 L min^{-1}) through a semi-closed rebreathing circle system. Ringer's acetate solution (SOLACET F; Terumo Corporation, Tokyo, Japan) was infused intravenously (5–8 ml kg^{-1} h^{-1}) through the cephalic vein. Inotropes and vasopressors were not administered during the procedure.

The patient was mechanically ventilated with a volume-control ventilator (PRO-NEXT +i/+s; ACOMA Medical Industry Co., Ltd., Tokyo, Japan) in the assist-control (A/C) mode. A continuous side-stream gas sampling system was attached between the endotracheal tube and the Y-piece of the breathing circuit. Ventilation parameters were adjusted to maintain partial pressure of end-tidal carbon dioxide ($P_Et'CO_2$) between 30 and 41 mm Hg (tidal volume [TV], 10–15 ml kg^{-1}; respiratory rate [f_R], 10–14 times min^{-1}; inspiratory/expiratory ratio, 1:2; positive end expiratory pressure (PEEP), 2 cm H_2O).

Intraoperative patient monitoring was performed using a multiparameter patient monitor with a built-in automated calibration system (Life Scope BSM-5192; Nihon Kohden Corporation, Tokyo, Japan) and a Masimo monitoring system (Radical-7; Masimo Corporation, Irvine, CA, USA). In summary, vital signs including heart rate, peripheral oxygen saturation (SpO_2), $P_Et'CO_2$, FiO_2, end-tidal sevoflurane concentration (F_Et'Sevo), invasive mean diastolic and systolic blood pressure, and oesophageal temperature were monitored throughout the procedure. Intraoperative records were made using an electronic anaesthesia record-keeping system (*paperChart*; https://paperchart.net/ech/), which was established by Dr. Masatsugu Echikawa (Department of Anesthesiology, Kobe Kaisei Hospital, Kobe, Japan), connected to a biological monitor as described earlier.

The emergency ovariohysterectomy was conducted uneventfully, and cardiorespiratory indices remained stable throughout the procedure. On completion of abdominal wall closure, the CRI of fentanyl was discontinued, and sevoflurane was decreased to an end-tidal concentration of 1.5%. Eight minutes after the discontinuation of fentanyl administration, skin closure and postoperative abdominal binding were completed, and sevoflurane was discontinued. During the weaning process, the patient was positioned in right lateral recumbency under the A/C mode of mechanical ventilation (TV, 10 ml kg^{-1}; f_R, 10–14; FiO_2, 1; and PEEP, 2 cm H_2O), and body temperature was maintained above 37.5°C. No specific abnormalities were observed in the cardiorespiratory indices at this stage.

2.1 | Diagnosis, treatment, and outcome

The anaesthesia chart and treatment course are shown in Figure 1. Ten minutes after the discontinuation of sevoflurane administration, no abnormalities were observed in the cardiorespiratory indices and capnogram under the A/C mode of mechanical ventilation (TV, 10 ml kg^{-1}; f_R, 10–14; FiO_2, 1; and PEEP, 2 cm H_2O).

Five minutes later, the investigator visually observed the increase in the peak inspiratory pressure using a pressure gauge. However, the eye position and palpebral reflex were unchanged, and other vital signs, including haemodynamic indices, were still within the normal range. The investigator (Kazumasu Sasaki) noticed jaw closure and stiffness (Figure 2a) (see Supporting Information Video), although it was not clear exactly when the symptoms had developed. In fact, the dog could not open and close its mouth and thus the endotracheal tube was intact. Furthermore, the thoraco-abdominal muscles tended to tense on palpation, and the dog was unable to rise. Changes in peak inspiratory pressure were not identified, and we concluded that the dog was unable to breathe spontaneously (Figure 2b). Continuous respiratory management under mechanical ventilation was required.

In order to rule out fentanyl-induced muscle rigidity, 0.02 mg kg^{-1} of IV naloxone (Naloxone Hydrochloride Intravenous Injection "Daiichi Sankyo"; Daiichi Sankyo Co., Ltd., Tokyo, Japan) was administered (Bednarski, 2015). The symptoms subsided after approximately 40–50 s, and the capnogram showed the return of spontaneous respiratory effort. Overall truncal muscle tone was recovered, and the relaxation of jaw tension and chest wall movement were confirmed. Based on the clinical signs and response to naloxone, we made a diagnosis of suspected fentanyl-induced muscle rigidity.

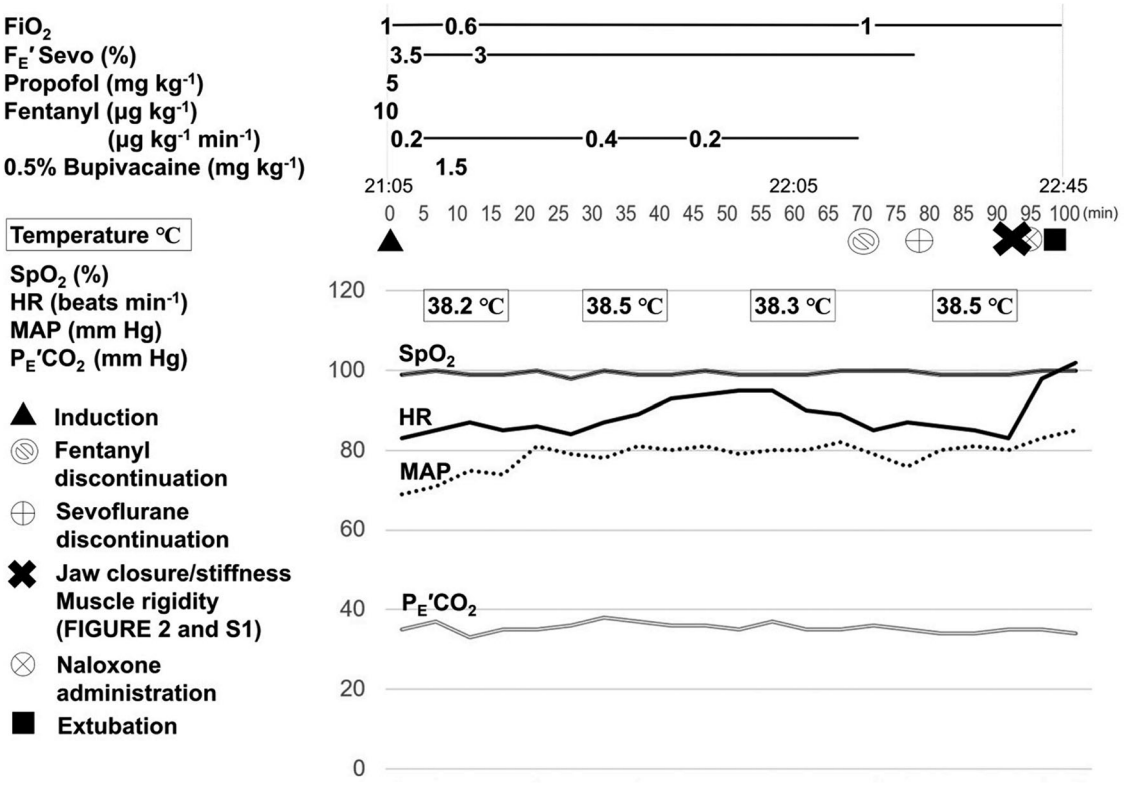

FIGURE 1 Anaesthesia chart and clinical course of the dog with suspected fentanyl-induced muscle rigidity. Abbreviations: FiO_2, fraction of inspired oxygen; FEt'Sevo, end-tidal sevoflurane concentration; HR, heart rate; MAP, mean arterial blood pressure; $PEt'CO_2$, partial pressure of end-tidal carbon dioxide; SpO_2, peripheral oxygen saturation

Six minutes later, the dog was extubated uneventfully without additional naloxone administration. Meloxicam (Inflacam 0.5%; Virbac Japan, Osaka, Japan) was administered subcutaneously as an alternative analgesic prior to extubation and hospitalization. Total anaesthesia duration (induction to extubation) was 99 min (CRI of fentanyl: 70 min; sevoflurane administration: 78 min), and 0.61 mg (27 μg kg^{-1}) of fentanyl, 112.5 mg (5 mg kg^{-1}) of propofol, 33.75 mg (1.5 mg kg^{-1}) of bupivacaine, and 199 ml of Ringer's acetate solution was administered.

During the 4-day postoperative hospitalization period, no opioids were administered, and no recurrent muscle rigidity was observed. Intensive postoperative pyometra management was successful, and the patient was safely discharged from our clinic.

3 | DISCUSSION

To our knowledge, this is the first description of fentanyl-induced muscle rigidity in a dog. Symptoms, including jaw muscle stiffness and thoraco-abdominal muscle rigidity, were observed during weaning from mechanical ventilation. A diagnosis of suspected fentanyl-induced muscle rigidity was made based on the reaction to naloxone. In humans, a variety of transient neurological signs including hyperreactive stretch reflexes, the Babinski reflex, shivering, and decerebrate posturing were reported during emergence from general anaesthesia with volatile anaesthetics including enflurane, halothane, nitrous oxide, and isoflurane (McCulloch & Milne, 1990; Rosenberg et al., 1981). The underlying mechanism remains unclear, but these observed actions may be the result of differential recovery rates of the central nervous system centres. Although there was limited opportunity to perform diagnosis by exclusion for central nervous system disorders owing to the urgency of the situation, we excluded the probability of these differential diagnoses based on the clinical symptoms and reaction to naloxone. Although relevant initial medical reports were published by Hamilton and Cullen in 1953 (Hamilton & Cullen, 1953), and clinical signs including chest wall rigidity and consequent respiratory depression are well recognized in people, it is quite rare and challenging to interpret the present case based on existing information. However, as described earlier, specific animal species, including rats (Sprague-Dawley rats and Wistar rats), rabbits (details of the strain were not described), guinea pigs, equids, and elk can also develop the aforementioned symptoms and, therefore, it is not surprising that a similar onset was observed in a dog. Although no deterministic factors have been disclosed in clinical settings in humans, we need to verify various factors to interpret the present rare case in a dog based on the medical and preclinical literature. Although it is difficult to identify correlations with specific physical conditions based on the current reports in humans, we speculate that since our patient had pyometra, the presence of underlying disease may be worth considering.

In humans, the patient background is diverse in terms of age, sex, and underlying disease. Bailey et al. (1985) reported that the

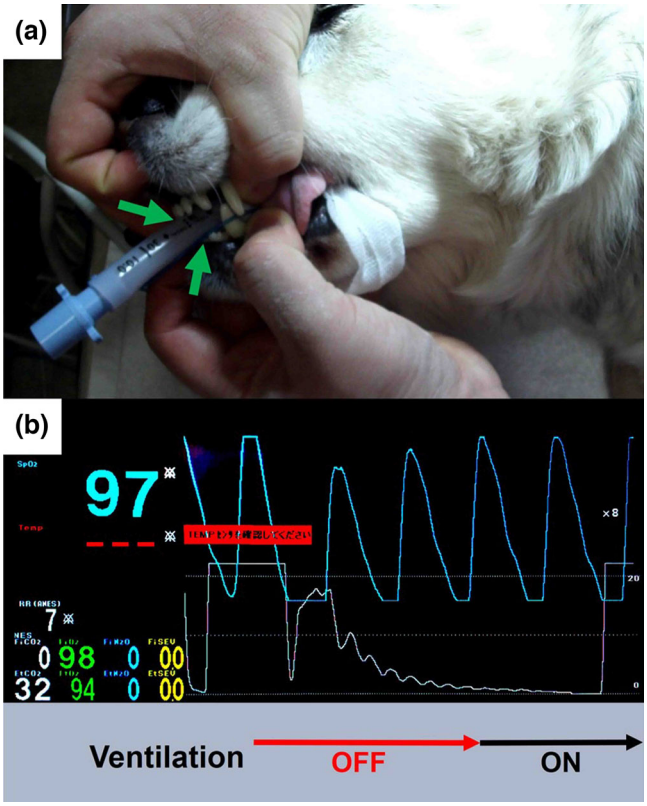

FIGURE 2 Jaw stiffness and apnoea in a dog with suspected fentanyl-induced muscle rigidity. Jaw stiffness was observed approximately 23 min after discontinuation of fentanyl administration (a). The investigator could not open and close the dog's mouth by hand and the dog could not chew off the tracheal tube (green arrow). To clarify the emergence of the spontaneous respiration waveform, we discontinued mechanical ventilation for a few seconds on a trial basis. No relevant waveform was confirmed before the administration of naloxone. Note that we temporarily set the upper limits of the capnogram value of the $PEt'CO_2$ as 20 mm Hg for visibility (b).

frequency of fentanyl-induced muscle rigidity onset increases with age; however, there is no consensus. Fentanyl-induced muscle rigidity has been reported in patients during sedation, general anaesthesia, and hospitalisation in the ICU (Tables S1 and S2). In veterinary medicine, there are currently no studies powered to evaluate the effects of breed, age, and sex on the development of fentanyl-induced muscle rigidity.

The relationship between drug dosage and symptom development should be considered, and conflicting results exist among human cases (Tables S1 and S2). It has been reported that the symptoms developed during high-dose fentanyl anaesthesia administration in patients undergoing cardiac surgery, including open heart, coronary artery bypass graft, myocardial revascularization, and valve repair in case reports (Christian et al., 1983; MacGregor & Bauman, 1996; Mirenda et al., 1988) and clinical trials (Jaffe & Ramsey, 1983), whereas even low doses of opioids resulted in development of symptoms (Dewhirst et al., 2012; Elakkumanan et al., 2008; Roy & Fortier, 2003). There is no consensus on this subject; thus, we could not discuss our case based on the administered dose. In fact, Soares et al. (2019) reported that a high (102 μg kg^{-1} loading dose; 0.8 μg kg^{-1} min^{-1} infusion) and low (33 μg kg^{-1} loading dose; 0.2 μg kg^{-1} min^{-1} infusion) dose of fentanyl under isoflurane anaesthesia for 60 min did not result in muscle rigidity in beagles. However, our patient developed symptoms within this range of fentanyl (10 μg kg^{-1} of induction, 0.2–0.4 μg kg^{-1} min^{-1} of CRI, total dose of 0.61 mg); thus, similar to studies reported in human medicine, development of fentanyl-induced muscle rigidity appears to be independent of the dose of fentanyl administered.

Symptoms associated with muscle and cardiorespiratory dysfunction (respiratory distress, hypotension, and asystole) were observed in some human patients who did not undergo tracheal intubation (Table S1). Anatomical locations, including the neck, jaw, chest, abdomen, and the whole body, were affected. In addition, some patients developed laryngeal, neck, and masseter muscle spasms. As a result of these symptoms, patients were unable to undergo spontaneous respiration, and ventilatory support was required. In animals, rigidity in the gastrocnemius soleus muscles of the hind limb (Blasco et al., 1986; Havemann & Kuschinsky, 1981; Havemann et al., 1980, 1982; Lui et al., 1990; Ossowska et al., 1986; Themann et al., 1984, 1986; Tsou et al., 1989; Turski et al., 1982a, 1982b, 1982c; Vankova et al., 1996; Wand et al., 1973; Wardas et al., 1987; Weinger et al., 1988, 1989, 1991, 1995), rectus abdominus muscles (Lui et al., 1989; Tsou et al., 1989), and sacrococcygeus dorsi lateralis muscles (Fu et al., 1994, 1997; Lai & Lui, 2000; Lee et al., 1995a, 1995b; Lui et al., 1993; Wang et al., 1994) were observed in rats, and chest wall compliance was decreased in rabbits (Soares et al., 2014). In guinea pigs, increased abdominal tone and rigidity have been observed (Brent & Bot, 1992). There are no reports on hemodynamic abnormalities in these species.

In addition to respiratory support by bag-assisted or mechanical ventilation, naloxone is commonly used for clinical diagnosis and treatment (Ackerman et al., 1990; Bowdle & Rooke, 1994; Chang & Fish, 1985; Çoruh et al., 2013; Fahnenstich et al., 2000; Lemmen & Semmekrot, 1996; Lynch & Hack, 2010; Phua et al., 2017; Roan et al., 2018; Rosenberg, 1977; van der Lee et al., 2009; Vaughn & Bennett, 1981) (Table S1). We administered naloxone for the treatment, and this approach is comparable with that used in humans. The symptoms improved immediately after naloxone administration.

As the symptoms developed in a client-owned dog in a private veterinary clinic, although we visually observed the changes in the peak inspiratory pressure using a pressure gauge, we did not have access to a diagnostic system with which we could evaluate muscle rigidity using quantitative measurements of chest wall compliance, as previously described in rabbits (Soares et al., 2014) and dogs (Soares et al., 2019). Naloxone may be useful in the diagnostic treatment of dogs, although we could not reach this conclusion from this report alone. Clinical trials have revealed that co-administration or pretreatment with barbiturates (Vacanti et al., 1991), muscle relaxant drugs (Hill et al., 1981; Nakada et al., 2009), and benzodiazepines (Mayumi et al., 1990; Sanford et al., 1994) in conjunction with opioids prevents, attenuates, or decreases the incidence and symptoms (Table S2). Although the effectiveness of these drugs remains unclear, their administration may be worth attempting in dogs.

4 | CONCLUSIONS

We presented the first case of suspected fentanyl-induced muscle rigidity in a client-owned mixed breed female dog. The symptoms and timing of onset were similar to those observed in humans, and the dog was successfully treated with naloxone. Although this was a rare case and risk factors for the development of symptoms remain unclear, veterinary clinicians should bear in mind that this species could develop this disorder.

AUTHOR CONTRIBUTIONS

Conceptualization, *data curation*, *investigation*, *supervision*, *writing—original draft*, *and writing—review and editing*: Kazumasu Sasaki. *Writing—review and editing*: Roberto Rabozzi. *Writing—review and editing*: Shinya Kasai. *Writing—review and editing*: Kazutaka Ikeda. *Resources and Writing—review and editing*: Tatsuya Ishikawa.

ACKNOWLEDGEMENTS

We would like to thank Editage (www.editage.jp) for English language editing. This study was supported by the Sendai Animal Care and Research Center Foundation and the intramural foundation of the Research Institute for Brain and Blood Vessels, Akita Cerebrospinal and Cardiovascular Center (21-01).

CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article, and further inquiries can be directed to the corresponding author.

ORCID

Kazumasu Sasaki https://orcid.org/0000-0003-3895-9973

PEER REVIEW

The peer review history for this article is available at https://publons.com/publon/10.1002/vms3.1001.

REFERENCES

Ackerman, W. E., Phero, J. C., & Theodore, G. T. (1990). Ineffective ventilation during conscious sedation due to chest wall rigidity after intravenous midazolam and fentanyl. *Anesthesia Progress*, *37*, 46–48.

Bailey, P. L., Wilbrink, J., Zwanikken, P., Pace, N. L., & Stanley, T. H. (1985). Anesthetic induction with fentanyl. *Anesthesia & Analgesia*, *64*, 48–53.

Bednarski, R. M. (2015). Dogs and cats. *Veterinary anesthesia and analgesia* (pp.819–826). Wiley-Blackwell.

Blasco, T. A., Lee, D., Amalric, M., Swerdlow, N. R., Smith, N. T., & Koob, G. F. (1986). The role of the nucleus raphe pontis and the caudate nucleus in alfentanil rigidity in the rat. *Brain Research*, *386*, 280–286.

Bowdle, T. A., & Rooke, G. A. (1994). Postoperative myoclonus and rigidity after anesthesia with opioids. *Anesthesia & Analgesia*, *78*, 783–786.

Brent, P. J., & Bot, G. (1992). Morphine, D-Pen2, D-Pen5 enkephalin and U50,488H differentially affect the locomotor activity and behaviours induced by quinpirole in guinea-pigs. *Psychopharmacology*, *107*, 581–590.

Chang, J., & Fish, K. J. (1985). Acute respiratory arrest and rigidity after anesthesia with sufentanil: A case report. *Anesthesiology*, *63*, 710–711.

Christian, C. M., 2nd, Waller, J. L., & Moldenhauer, C. C. (1983). Postoperative rigidity following fentanyl anesthesia. *Anesthesiology*, *58*, 275–277.

Çoruh, B., Tonelli, M. R., & Park, D. R. (2013). Fentanyl-induced chest wall rigidity. *Chest*, *143*, 1145–1146.

Dewhirst, E., Naguib, A., & Tobias, J. D. (2012). Chest wall rigidity in two infants after low-dose fentanyl administration. *Pediatric Emergency Care*, *28*, 465–468.

Elakkumanan, L. B., Punj, J., Talwar, P., Rajaraman, P., Pandey, R., & Darlong, V. (2008). An atypical presentation of fentanyl rigidity following administration of low dose fentanyl in a child during intraoperative period. *Paediatric Anaesthesia*, *18*, 1115–1117.

Fahnenstich, H., Steffan, J., Kau, N., & Bartmann, P. (2000). Fentanyl-induced chest wall rigidity and laryngospasm in preterm and term infants. *Critical Care Medicine*, *28*, 836–839.

Fu, M. J., Lin, T. C., Lui, P. W., Lee, T. Y., & Chan, S. H. (1994). Involvement of G(o) alpha subtype of guanine nucleotide-binding regulatory protein at the locus coeruleus in fentanyl-induced muscular rigidity in the rat. *Neuroscience Letters*, *165*, 199–202.

Fu, M. J., Tsen, L. Y., Lee, T. Y., Lui, P. W., & Chan, S. H. (1997). Involvement of cerulospinal glutamatergic neurotransmission in fentanyl-induced muscular rigidity in the rat. *Anesthesiology*, *87*, 1450–1459.

Hamilton, W. K., & Cullen, S. C. (1953). Effect of levallorphan tartrate upon opiate induced respiratory depression. *Anesthesiology*, *14*, 550–554.

Havemann, U., & Kuschinsky, K. (1981). Further characterization of opioid receptors in the striatum mediating muscular rigidity in rats. *Naunyn-Schmiedeberg's Archieves of Pharmacology*, *317*, 321–325.

Havemann, U., Turski, L., & Kuschinsky, K. (1982). Role of GABAergic mechanisms in the substantia nigra pars reticulata in modulating morphine-induced muscular rigidity in rats. *Neuroscience Letters*, *31*, 25–30.

Havemann, U., Winkler, M., & Kuschinsky, K. (1980). Opioid receptors in the caudate nucleus can mediate EMG-recorded rigidity in rats. *Naunyn-Schmiedeberg's Archives of Pharmacology*, *313*, 139–144.

Hill, A. B., Nahrwold, M. L., de Rosayro, A. M., Knight, P. R., Jones, R. M., & Bolles, R. E. (1981). Prevention of rigidity during fentanyl–oxygen induction of anesthesia. *Anesthesiology*, *55*, 452–454.

Jaffe, T. B., & Ramsey, F. M. (1983). Attenuation of fentanyl-induced truncal rigidity. *Anesthesiology*, *58*, 562–564.

Knych, H. K., Steffey, E. P., Casbeer, H. C., & Mitchell, M. M. (2015). Disposition, behavioural and physiological effects of escalating doses of intravenously administered fentanyl to young foals. *Equine Veterinary Journal*, *47*, 592–598.

Lai, S., & Lui, P. (2000). Inhibition by neuropeptide Y of fentanyl-induced muscular rigidity at the locus coeruleus in rats. *Neuroscience Letters*, *280*, 203–206.

Lee, T. Y., Fu, M. J., Lui, P. W., & Chan, S. H. (1995a). Involvement of potassium and calcium channels at the locus coeruleus in fentanyl-induced muscular rigidity in the rat. *Neuroscience Letters*, *199*, 195–198.

Lee, T. Y., Fu, M. J., Lui, P. W., & Chan, S. H. (1995b). Subtypes of guanine-nucleotide-binding regulatory proteins at the locus coeruleus involved in fentanyl-induced muscular rigidity in the rat. *Journal of Biomedical Science*, *2*, 263–271.

Lemmen, R. J., & Semmekrot, B. A. (1996). Muscle rigidity causing life-threatening hypercapnia following fentanyl administration in a premature infant. *European Journal of Pediatrics*, *155*, 1067.

Lui, P. W., Chang, G. J., Lee, T. Y., & Chan, S. H. (1993). Antagonization of fentanyl-induced muscular rigidity by denervation of the coerulospinal noradrenergic pathway in the rat. *Neuroscience Letters*, *157*, 145–148.

Lui, P. W., Lee, T. Y., & Chan, S. H. (1989). Involvement of locus coeruleus and noradrenergic neurotransmission in fentanyl-induced muscular rigidity in the rat. *Neuroscience Letters*, *96*, 114–119.

Lui, P. W., Lee, T. Y., & Chan, S. H. (1990). Involvement of coerulospinal noradrenergic pathway in fentanyl-induced muscular rigidity in rats. *Neuroscience Letters*, *108*, 183–188.

Lynch, R. E., & Hack, R. A. (2010). Methadone-induced rigid-chest syndrome after substantial overdose. *Pediatrics*, *126*, e232–234.

MacGregor, D. A., & Bauman, L. A. (1996). Chest wall rigidity during infusion of fentanyl in a two-month-old infant after heart surgery. *Journal of Clinical Anesthesia*, *8*, 251–254.

Mayumi, T., Matsumiya, N., Fujita, S., & Dohi, S. (1990). Diazepam prevents fentanyl-induced muscle rigidity. *Journal of Anesthesia*, *4*, 82–84.

McCulloch, P. R., & Milne, B. (1990). Neurological phenomena during emergence from enflurane or isoflurane anaesthesia. *Canadian Journal of Anaesthesia*, *37*, 739–742.

Ming, P. W., & Singh, D. L. (2019). Fentanyl-induced chest wall rigidity as a cause of acute respiratory failure in the intensive care unit. *Journal of Medical Cases*, *10*, 249–252.

Mirenda, J., Tabatabai, M., & Wong, K. (1988). Delayed and prolonged rigidity greater than 24 h following high-dose fentanyl anesthesia. *Anesthesiology*, *69*, 624–625.

Nakada, J., Nishira, M., Hosoda, R., Funaki, K., Takahashi, S., Matsura, T., & Inagaki, Y. (2009). Priming with rocuronium or vecuronium prevents remifentanil-mediated muscle rigidity and difficult ventilation. *Journal of Anesthesia*, *23*, 323–328.

Ossowska, K., Wardas, J., Warchał, D., Kolasiewicz, W., & Wolfarth, S. (1986). GABA mechanisms of ventromedial thalamic nucleus in morphine-induced muscle rigidity. *European Journal of Pharmacology*, *129*, 245–251.

Paterson, J. M., Caulkett, N. A., & Woodbury, M. R. (2009). Physiologic effects of nasal oxygen or medical air administered prior to and during carfentanil-xylazine anesthesia in North American elk (*Cervus canadensis manitobensis*). *Journal of Zoo and Wildlife Medicine*, *40*, 39–50.

Phua, C. K., Wee, A., Lim, A., Abisheganaden, J., & Verma, A. (2017). Fentanyl-induced chest wall rigidity syndrome in a routine bronchoscopy. *Respiratory Medicine Case Reports*, *20*, 205–207.

Roan, J. P., Bajaj, N., Davis, F. A., & Kandinata, N. (2018). Opioids and chest wall rigidity during mechanical ventilation. *Annals of Internal Medicine*, *168*, 678.

Rosenberg, H., Clofine, R., & Bialik, O. (1981). Neurologic changes during awakening from anesthesia. *Anesthesiology*, *54*, 125–130.

Rosenberg, M. (1977). Muscle rigidity with fentanyl: A case report. *Anesthesia Progress*, *24*, 50–52.

Roy, S., & Fortier, L. P. (2003). Fentanyl-induced rigidity during emergence from general anesthesia potentiated by venlafexine. *Canadian Journal of Anaesthesia*, *50*, 32–35.

Sanford, T. J., Jr., Weinger, M. B., Smith, N. T., Benthuysen, J. L., Head, N., Silver, H., & Blasco, T. A. (1994). Pretreatment with sedative-hypnotics, but not with nondepolarizing muscle relaxants, attenuates alfentanil-induced muscle rigidity. *Journal of Clinical Anesthesia*, *6*, 473–480.

Soares, J. H., Brosnan, R. J., Smith, A., & Mayhew, P. D. (2014). Rabbit model of chest wall rigidity induced by fentanyl and the effects of apomorphine. *Respiratory Physiology & Neurobiology*, *202*, 50–52.

Soares, J. H., Henao-Guerrero, N., Pavlisko, N. D., Williamson, A., & Giannella-Neto, A. (2019). The effect of two doses of fentanyl on chest wall rigidity at equipotent doses of isoflurane in dogs. *Veterinary Anaesthesia and Analgesia*, *46*, 360–364.

Themann, P., Havemann, U., & Kuschinsky, K. (1984). Development of tolerance to the muscular rigidity produced by morphine and replacement by stereotypic behaviour. *Neuropeptides*, *5*, 27–28.

Themann, P., Havemann, U., & Kuschinsky, K. (1986). On the mechanisms of the development of tolerance to the muscular rigidity produced by morphine in rats. *European Journal of Pharmacology*, *129*, 315–321.

Trujillo, C., Rudd, D., Ogutcu, H., Dong, F., Wong, D., & Neeki, M. (2020). Objective characterization of opiate-induced chest wall rigidity. *Cureus*, *12*, e8459.

Tsou, M. Y., Lui, P. W., Lee, T. Y., Pan, J. T., & Chan, S. H. (1989). Differential effects of prazosin and yohimbine on fentanyl-induced muscular rigidity in rats. *Neuropharmacology*, *28*, 1163–1168.

Turski, L., Havemann, U., & Kuschinsky, K. (1982a). Evidence for functional interactions of morphine in substantia nigra and striatum in relation to muscular rigidity in rats. *Neuroscience Letters*, *28*, 291–296.

Turski, L., Havemann, U., & Kuschinsky, K. (1982b). On the possible role of excitatory amino acids in the striatum in mediating morphine-induced muscular rigidity. *Pharmacology Biochemistry and Behavior*, *17*, 715–719.

Turski, L., Havemann, U., Schwarz, M., & Kuschinsky, K. (1982c). Disinhibition of nigral GABA output neurons mediates muscular rigidity elicited by striatal opioid receptor stimulation. *Life Sciences*, *31*, 2327–2330.

Vacanti, C. A., Silbert, B. S., & Vacanti, F. X. (1991). The effects of thiopental sodium on fentanyl-induced muscle rigidity in a human model. *Journal of Clinical Anesthesia*, *3*, 395–398.

van der Lee, R., Ceelie, I., & de Wildt, S. N. (2009). Morphine-induced muscle rigidity in a term neonate. *Annals of Pharmacotherapy*, *43*, 1724–1726.

Vankova, M. E., Weinger, M. B., Chen, D. Y., Bronson, J. B., Motis, V., & Koob, G. F. (1996). Role of central mu, delta-1, and kappa-1 opioid receptors in opioid-induced muscle rigidity in the rat. *Anesthesiology*, *85*, 574–583.

Vaughn, R. L., & Bennett, C. R. (1981). Fentanyl chest wall rigidity syndrome—A case report. *Anesthesia Progress*, *28*, 50–51.

Wand, P., Kuschinsky, K., & Sontag, K. H. (1973). Morphine-induced muscular rigidity in rats. *European Journal of Pharmacology*, *24*, 189–193.

Wang, S. W., Tsou, M. Y., Lee, T. Y., Chan, S. H., & Lui, P. W. (1994). Antagonization of fentanyl-induced muscular rigidity by neurotensin at the locus coeruleus of the rat. *Regulatory Peptides*, *51*, 33–40.

Wardas, J., Ossowska, K., & Wolfarth, S. (1987). The role of gamma-aminobutyric acid mechanisms of the zona incerta-lateral hypothalamus in the catalepsy and muscle rigidity evoked by morphine. *Brain Research*, *408*, 363–366.

Weinger, M. B., Chen, D. Y., Lin, T., Lau, C., Koob, G. F., & Smith, N. T. (1995). A role for CNS alpha-2 adrenergic receptors in opiate-induced muscle rigidity in the rat. *Brain Research*, *669*, 10–18.

Weinger, M. B., Cline, E. J., Smith, N. T., Blasco, T. A., & Koob, G. F. (1988). Localization of brainstem sites which mediate alfentanil-induced muscle rigidity in the rat. *Pharmacology Biochemistry and Behavior*, *29*, 573–580.

Weinger, M. B., Segal, I. S., & Maze, M. (1989). Dexmedetomidine, acting through central alpha-2 adrenoceptors, prevents opiate-induced muscle rigidity in the rat. *Anesthesiology*, *71*, 242–249.

Weinger, M. B., Smith, N. T., Blasco, T. A., & Koob, G. F. (1991). Brain sites mediating opiate-induced muscle rigidity in the rat: Methylnaloxonium mapping study. *Brain Research*, *544*, 181–190.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Sasaki, K., Rabozzi, R., Kasai, S., Ikeda, K., & Ishikawa, T. (2023). Fentanyl-induced muscle rigidity in a dog during weaning from mechanical ventilation after emergency abdominal surgery: A case report. *Veterinary Medicine and Science*, *9*, 37–42.
https://doi.org/10.1002/vms3.1001