Case Report

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Ventilatory failure in a cat following radical chest wall resection for feline injection site sarcoma

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Abstract

Case summary A 12-year-old spayed female domestic shorthair cat presented for chest wall resection and radiation therapy following incomplete surgical excision of a feline injection site sarcoma. A CT scan for surgical planning was performed under general anesthesia and showed extensive tumor infiltration of the soft tissues of the right thorax. The cat recovered uneventfully from this anesthetic event. Nineteen days later, the patient was reanesthetized for forequarter amputation plus radical chest wall resection, including ribs 3–8 and all associated soft tissues plus adjacent spinous processes. Postoperatively, the patient developed acute respiratory failure secondary to hypoventilation. The cat was mechanically ventilated for 12 h prior to being successfully weaned from the ventilator. However, the improvement was transient and mechanical ventilation was reinitiated 6 h later owing to respiratory fatigue. On the second day, the cat developed unexplained central nervous system signs and was euthanized.

Relevance and novel information To our knowledge, this is the first case report to describe ventilatory failure secondary to radical chest wall resection in a cat. Hypoventilation with subsequent need for mechanical ventilation is a potential complication that should be considered during preoperative planning in patients requiring extensive chest wall resections.

Keywords: Injection-site sarcoma; rib resection; chest wall resection; mechanical ventilation; respiratory failure

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Introduction

Thoracic wall resection is commonly performed for the management of infiltrative thoracic tumors, such as feline injection site sarcoma (FISS). These are locally aggressive mesenchymal tumors that develop at sites of previous injections.[1,2] Owing to their infiltrative biologic behavior, early and radical surgery is a key therapeutic step along with adjunctive oncologic techniques to provide a comprehensive management strategy.[3–5] Recommendations for resection include 3–5 cm lateral margins and two fascial planes deep to optimize tumor-free interval.[4,6–8] Depending upon the location, radical resection may include partial or complete scapulectomy, forequarter amputation and resection of multiple ribs with adjacent musculature.[6,9] Primary repair of the resulting large defect following a radical tumor resection can be challenging, and, where thoracic wall resection is performed, a key part of reconstruction is restoration of a sufficiently rigid chest wall to prevent ventilatory compromise.[10]

In humans, radical chest wall resection is defined as resection of five or more consecutive ribs requiring reconstruction to restore chest wall stability.[11] The size of the defect rather than the method of reconstruction is the most significant predictor of complication rate (11–31%), although overall mortality is low (3–7%).[12–14] In companion animals, the term 'radical resection' has not been defined and there is little published information available

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regarding the safety of extensive chest wall resection and reconstruction in these patients. Reported complications include infection of reconstructive mesh, dehiscence and pneumothorax.[6,15,16] However, the fatal complication rate has been reported to be <5%.[4,17] While several prior reports have documented the safe removal of up to six ribs from dogs[13,18] and seven ribs in cats[4] (J Liptak, 2021, personal communication), postoperative cardiopulmonary arrest has also been reported following removal of three ribs in a cat[9] and four ribs in a dog.[16] No publication to date has specifically described radical chest wall resection (defined as removal of five or more consecutive ribs) as a cause of ventilatory failure in cats.

Case description

A 12-year-old spayed female domestic shorthair cat weighing 3.6 kg presented to the University of Minnesota Veterinary Medical Center (VMC) for evaluation of recurrent FISS of the right scapula. The tumor was first noted by the primary veterinarian as a 1 cm × 1 cm × 1 cm movable mass on the dorsal border of the right scapula. It was marginally removed, and histopathology revealed an incompletely excised FISS. Tumor recurrence was noted 7 months later, and the cat was referred to the VMC.

Upon initial physical examination, a small (dimensions not noted), firm, movable, multilobulated subcutaneous mass immediately caudal to the right scapula was appreciated. No other abnormalities were detected. Routine preoperative bloodwork was collected and showed no abnormalities other than a moderately low platelet count (53,000/µl; reference interval [RI] 110,000–413,000). Coagulation analysis revealed a factor XII deficiency. D-dimer was 229 ng/ml (RI <250). Owing to scheduling constraints, advanced imaging was arranged for the following month.

At re-presentation (19 days later), the mass was measured at 3 cm × 2 cm × 1 cm, with a second nodule and another cluster of smaller nodules detected immediately cranial to the main mass. The remainder of the physical examination was unchanged. The patient was anesthetized for CT of the neck and chest for surgical planning. The patient was premedicated with intramuscular butorphanol (0.4 mg/kg) and dexmedetomidine (3 µg/kg). Anesthesia was induced with propofol (2.5 mg/kg IV) and maintained with isoflurane in oxygen. The cat breathed spontaneously throughout the procedure and recovery was uneventful. CT revealed multiple irregularly shaped, lobulated, soft tissue-attenuating masses affecting the right latissimus dorsi muscle, right thoracic subcutaneous structures and right serratus ventralis muscle, with the largest measuring 2.7 cm × 1.8 cm × 1.3 cm (Figure 1). There was no evidence of nodal or pulmonary metastasis. The initial recommendation to the client was radiation followed by surgery and chemotherapy, but this plan was declined for financial reasons. As a result, a surgery-only option was offered to the owner, with an understanding that there was a higher risk of morbidity with this approach. Re-excision of the tumor via right forequarter amputation, spinous process ostectomies (3–8) and rib resections (3–8) was scheduled to take place 4 days later.

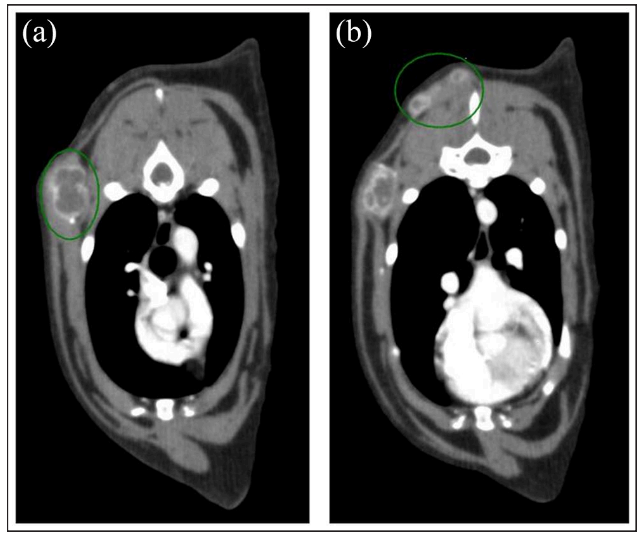

Figure 1 Preoperative thoracic CT scan, post-contrast, transverse view. (a) The main tumor (green circle) within the subcutaneous tissues of the right body wall. (b) Additional nodules (green circle) extend at their most proximal aspect to the spinous process of T8

On the morning of the procedure, a platelet count was within normal limits, but a preoperative packed cell volume (PCV) revealed a new anemia of 23% and total protein of 4.8 g/dl. A complete blood count to further characterize the anemia was not performed at this time. Coinduction was performed intravenously with a combination of fentanyl (5 µg/kg), midazolam (0.2 mg/kg), ketamine (2 mg/kg) and propofol (1.5 mg/kg), and maintained with isoflurane in oxygen along with constant rate infusions of fentanyl (10–20 µg/kg/h) and ketamine (2 mg/kg/h). A right-sided brachial plexus block was performed using bupivacaine (2.5 mg) and dexmedetomidine (2.5 µg). Invasive blood pressure (IBP), pulse oximetry (SpO_2) and end-tidal carbon dioxide ($ETCO_2$) were continuously monitored. A mechanical ventilator (MV) was used for the duration of surgery. Episodes of hypotension were treated with balanced crystalloid (lactated Ringer's solution; Hospira) and tetrastarch (VetStarch; Zoetis) boluses, dopamine and atropine. A unit each of type- and crossmatch-compatible packed red blood cells and fresh frozen plasma were sequentially administered during the procedure to treat the pre-existing anemia and proactively manage the potential for significant intraoperative blood loss.

Intraoperatively, 5 cm surgical margins were outlined around the primary mass and satellite lesions, based on

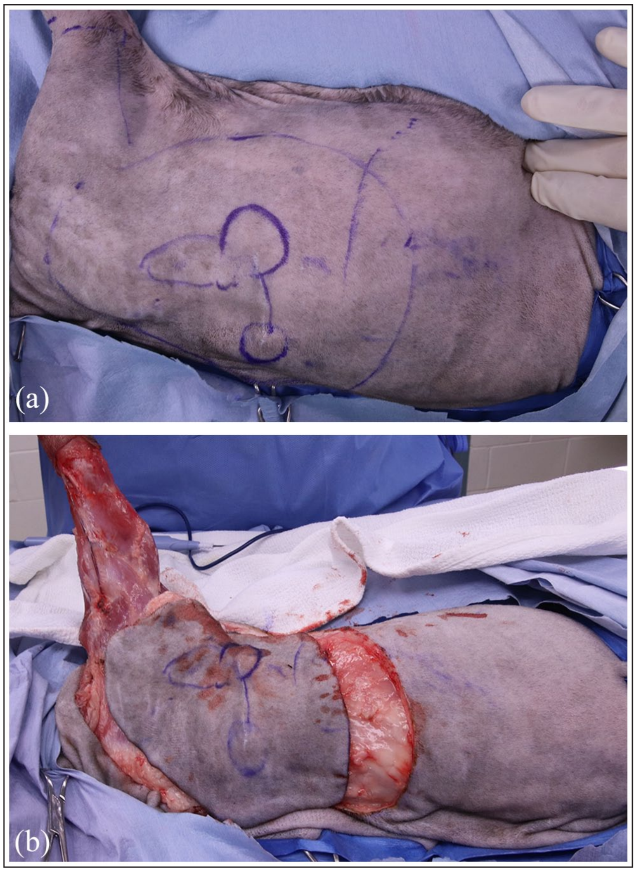

Figure 2. (a) Intraoperative photo of the planned surgical site based on the main mass and satellite tumors, assisted by CT planning. A sterile marking pen was used to mark the palpable masses and 5 cm lateral margins. The patient was in left lateral recumbency with the head to the left and dorsal at the bottom of the image. (b) Circumferential skin incision around the planned site. The patient was in left lateral recumbency with the head to the left and dorsal at the bottom of the image

a combination of palpation and CT guidance (Figure 2). A standard right forequarter amputation was performed with the surgical borders extending from the deep pectoralis muscles ventrally and medially to the contralateral muscles of spinous processes of vertebrae 3–8 dorsally, as well as from the right second intercostal space cranially to the right eighth intercostal space caudally, leaving the ninth rib in situ. Intercostal nerve blocks of ribs 3–8 were performed with bupivacaine. These ribs were disarticulated and removed to the level of the costochondral junction along with the associated dorsal spinous processes, thoracic wall and right forelimb en bloc (Figure 3). An omental flap was prepared via a right paracostal flank approach and passed into the chest, then sutured to the body wall covering the lungs. A single layer of polypropylene mesh (Bard monofilament; Davol) was fitted to the defect and sutured to the body wall using 3-0 PDS in a horizontal mattress pattern,

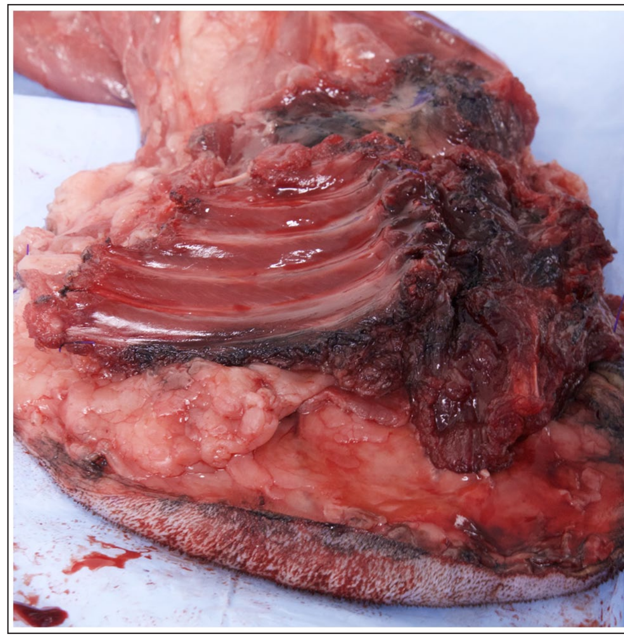

Figure 3 En bloc resected portion of the right thoracic wall, including ribs 3–8, spinous process ostectomies 3–8 and right forequarter amputation. The thoracic limb extends toward the top of the image and out of frame. The caudal-most aspect of the resection is in the foreground of the image

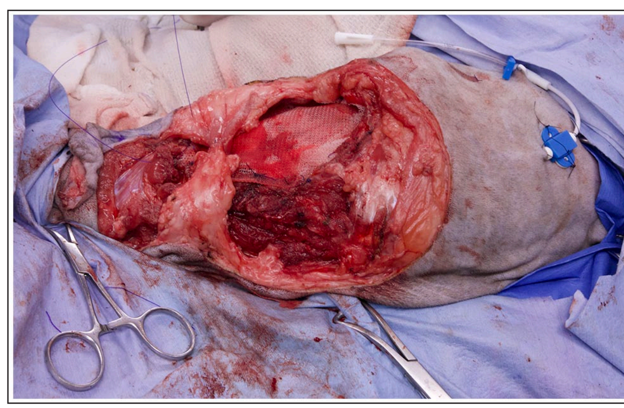

Figure 4 The defect in the chest wall was repaired with an omental flap and polypropylene mesh (visible at the center of the defect) sutured to the body wall. The subcutaneous tissue was closed atop this layer. A thoracostomy tube was placed through the caudodorsal chest wall. The dorsal and cranial aspects of the surgical field are to the bottom and left of the image, respectively

incorporating the omental layer (Figure 4). The deep adipose and subcutaneous layers were apposed with 3-0 PDS in a simple continuous pattern. The skin was closed with 3-0 Nylon in a cruciate pattern (Figure 5). A 14 G thoracostomy tube (#CT1410; MILA International) was placed using the modified Seldinger technique. The tube was suctioned until negative pressure was established. Total surgical time was approximately 4 h 30 mins.

Figure 5 Final closure with thoracostomy tube in place. The dorsal and cranial aspects of the surgical field are to the bottom and left of the image, respectively

No excessive bleeding was noted during surgery. The post-transfusion, postoperative PCV was 30%, and postoperative temperature was 90.9°F (32.7°C).

The cat was successfully weaned from vasopressor support 30 mins after the end of surgery. Recovery from anesthesia was prolonged, prompting partial antagonism of fentanyl with butorphanol (0.2 mg/kg IV) 2 h post-procedure. At 5 h post-procedure, the patient remained too sedated to be safely extubated, but was disconnected from the anesthesia ventilator to test respiratory ability. During spontaneous inspiration, there was a visibly asynchronous respiratory pattern with minimal expansion of the right chest wall. The cat immediately desaturated (SpO_2 80%) and therefore manual assisted breathing was instituted. In an attempt to eliminate the confounding effect of drugs on recovery, an additional 4 h of assisted manual ventilation were provided, during which there was no improvement in mentation or respiratory effort. When disconnection was attempted again during transfer to the intensive care unit (ICU), the cat quickly became hypoxemic (PaO_2 70 mmHg) and hypercapnic ($PaCO_2$ 88 mmHg). At that time, MV with a critical care ventilator (Respironics V200; Philips) was initiated. The patient's temperature had increased to 97.2°F (36.2°C), but its mentation remained stuporous and the gag reflex was minimal.

Initially, the ventilator mode was set to pressure-controlled, synchronized intermittent mandatory ventilation. $ETCO_2$ normalized almost immediately. The fraction of inspired oxygen (FiO_2) was decreased to 0.6 within 1 h, which was sufficient to maintain SpO_2 at 98–100%. Arterial blood gas samples were collected for serial monitoring (Table 1). Ventilator settings were adjusted to maintain a $PaCO_2$ of 35–45 mmHg and PaO_2 of >90 mmHg. Additional therapies consisted of ampicillin sulbactam (30 mg/kg IV) due to the prolonged surgical time, fentanyl (1 µg/kg/h) and ketamine (1 µg/kg/min) for postoperative analgesia. The cat remained stuporous despite subtherapeutic doses of sedatives and no dosage increases were required overnight. The following morning, chest wall excursions during periods of spontaneous breathing were subjectively improved. The ventilator mode was changed to continuous positive airway pressure ventilation with pressure support prior to successful ventilator weaning. In total, the cat was mechanically ventilated for 12 h.

Upon extubation, the cat was placed in an oxygen cage set to FiO_2 0.6. Only a low-dose ketamine infusion (1 µg/kg/min) was maintained for analgesia. Monitoring with an electrocardiogram, IBP, SpO_2 and rectal thermometer were continued. The patient was breathing well initially (PaO_2 293 mmHg, $PaCO_2$ 42 mmHg, estimated FiO_2 0.7) but became progressively hypercapnic ($PaCO_2$ 58 mmHg). After 6 h, given the concern for respiratory muscle fatigue, the patient was reintubated and placed back on the ventilator with similar settings as before. At this time, the cat was more alert and required additional drugs to remain intubated. Fentanyl was restarted (2 µg/kg/h) and ketamine was increased (2 µg/kg/min). Overnight, these doses were doubled to achieve an adequate plane of anesthesia.

The next morning, the cat developed anisocoria, characterized by mydriasis in the left eye and miosis in the right eye. Pupillary light reflexes were intact but slow. A dazzle reflex was present bilaterally. No other cranial nerve abnormalities were noted. A drop of 1% phenylephrine was administered into the right eye to rule out Horner's syndrome as a cause of miosis. No response was appreciated and therefore an intracranial cause of anisocoria was deemed most likely. The owner was contacted and, owing to the guarded prognosis for long-term ventilatory ability, elected for euthanasia.

Necropsy revealed no apparent cause of the central nervous system signs on gross or histologic examination. Variable amounts of fibrin were found within multiple organs, including blood vessels within the cerebrum, brainstem and spinal cord. Several areas of hemorrhage were identified, including within the omental flap, subcutaneous ventral thorax, and intravenous and arterial catheter sites. The lungs contained areas of multifocal, mild alveolar congestion and edema without evidence of atelectasis. The chest wall reconstruction with mesh and omental flap were intact without evidence of complications.

Discussion

This is the first report to describe ventilatory failure as a complication of feline radical chest wall resection. Although the outcome was ultimately unsuccessful, MV was temporarily able to resolve the patient's hypoxemia and hypercapnia. Subsequently, the cat was transiently weaned from the ventilator and breathed spontaneously for 6 h before developing respiratory muscle fatigue that required additional intervention.

Table 1 Selected arterial blood gases (and ventilator settings where applicable) showing trends in parameters from end anesthesia (time 0), during anesthetic recovery, mechanical ventilation (MV) and the spontaneous breathing trial

Time (h postoperatively)	0	5	9	10	17	20	22	27	28	
Comment	End of anesthesia	Disconnected from anesthesia ventilator	O_2 cage (transfer to ICU)	Initiate MV		Begin weaning protocol	O_2 cage + flow-by mask	O_2 cage	Re-initiate MV	RI (arterial)
Ventilator mode	Manual assist			SIMV (PC)	SIMV (PC)	CPAP (PSV)			SIMV (PC)	
SaO_2 (%)	100	80	84	95	99	98	100	97	97	95–98
FiO_2	1.0	0.6	0.6	0.6	0.5	0.4	0.7 (est)	0.6	1.0	
PaO_2 (mmHg)	283	55	70	90	153	112	293	117	388	73.7–100.2
$PaCO_2$ (mmHg)	39	58	88	46	29	29	42	58	39	24.1–37.3
$ETCO_2$ (mmHg)	30	50	62	42	26	26	39	55	35	
RR (breaths/min)	20	10	16	34	17	15	15	24	15	
PEEP (cmH_2O)				5	5	5			5	
PSV (cmH_2O)				6	6	4			6	
I:E ratio				1:2.3	1:2.9	1:3.4			1:2.6	
PIP (cmH_2O)				16	15.9	17.5			18.2	
V_{min} (ml/kg/min)				160	165	128			138	

ICU = intensive care unit; RI= reference interval; SIMV = synchronized intermittent mandatory ventilation; PC = pressure control; CPAP = continuous positive airway pressure ventilation; SaO_2 = arterial oxygen saturation; FiO_2 = fraction of inspired oxygen; est = estimated value; PaO_2 = partial pressure of arterial oxygen; $PaCO_2$ = partial pressure of arterial carbon dioxide; $ETCO_2$ = end-tidal carbon dioxide; RR = respiratory rate; PEEP = positive end expiratory pressure; PSV = pressure support ventilation; I:E ratio = ratio of inspiratory time to expiratory time; PIP = peak inspiratory pressure; V_{min} = minute ventilation

Ventilation is controlled by the mechanical properties of the lung (airways, parenchyma, interstitium and alveoli) and chest wall (rib cage, diaphragm and cranial abdominal muscles).[19] The interaction between these forces determines lung volume and ventilation effectiveness. While normal expiration is a passive process, inspiration requires musculature and ribs to provide the force and structure necessary for chest volume expansion.[20,21] The diaphragm and external intercostal muscles are the primary inspiratory muscles, while accessory muscles of inspiration include the scalenes, serratus ventralis and other small muscles of the head and neck.[19]

In this patient, the attachment sites of the muscular portion of the diaphragm (lumbar vertebrae, caudal ribs and sternum) and the phrenic nerves were not damaged during surgery, and therefore diaphragmatic function should have remained intact. However, the majority of the right-sided external intercostal muscles were resected, resulting in a large thoracic wall defect. In humans, extensive defects are reconstructed with either a single sheet of polytetrafluoroethylene mesh, or via the 'sandwich technique', where a methyl methacrylate prosthesis is surrounded by two sheets of polypropylene mesh.[11] Both techniques are reported to provide excellent functional chest stability.[11] In our patient, a single sheet of polypropylene mesh was used, which is the most common technique reported in the veterinary literature.[9,10,15,16] However, it is possible that a more rigid prosthesis may have provided a better mechanical outcome in this patient.

Chest wall resection has been reported to have a variable complication rate. In one study of 48 cats undergoing surgical resection of FISS (40 with an average of 3.5 ribs removed, and eight with an average of 4.4 ribs removed), only four cats (each with four ribs removed) died from cardiopulmonary arrest within 2–4 days postoperatively.[4] Lidbetter et al[9] described a cat with difficulty weaning from the ventilator after having three ribs resected. This cat arrested shortly after and was successfully resuscitated; the arrest was attributed to a combination of hypothermia and a tight chest bandage. The other two cats requiring three rib resections in this report survived without complication. The maximum number of ribs reported to be removed from a cat en bloc is seven consecutive ribs, and this cat was reported to have survived the immediate postoperative period.[4] The cat in the current report was never able to breathe satisfactorily after the removal of six ribs.

The principle cause of the cat's breathing difficulty was attributed to the loss of thoracic rigidity and integrity following the surgical resection of a large number of consecutive ribs. Other potential contributors to the cat's respiratory muscle weakness following surgery could also be considered, though if any of these were present, their impact on the cat's breathing ability were likely to have been minimal. These factors include ventilator-induced diaphragmatic dysfunction, delayed anesthesia recovery secondary to prolonged anesthesia time and hypothermia, and acute neurologic disease.

Ventilator-induced diaphragmatic dysfunction, which results in decreased force-generating capacity, has been shown to occur even after a short duration of ventilation.[22–24] Animal studies and more recent findings in humans suggest it may also affect the intercostal muscles.[25–27] This cat received assisted ventilation for a total time of around 14 h, consisting of approximately 1 h of assisted manual ventilation during the preparatory phase, 9 h on an anesthesia ventilator (including surgical time and postoperative recovery time) and assisted manual ventilation for an additional 4 h postoperatively, until it was placed on MV in the ICU where it was ventilated for an additional 12 h. Recovery strategies in mechanically ventilated humans may include daily spontaneous breathing trials (SBTs) of 30–120 mins to strengthen the inspiratory muscles.[28] A similar SBT in this patient was successful in allowing transient discontinuation of MV for 6 h. However, the existence of ventilator-induced diaphragmatic dysfunction in this cat is speculative. If present, it was unlikely to have played a significant role in this cat's breathing difficulty because it does not explain the redevelopment of ventilatory failure in this cat following a period of spontaneous breathing.

Another consideration is whether the prolonged anesthesia time and the resulting large cumulative dose of injectable agents were associated with this cat's hypoventilation and slow recovery from anesthesia. Hypothermia further compromises drug metabolism and clearance, and this may have prolonged the respiratory depressant effects of some of the anesthetic drugs.[29] However, on the whole, these factors would have had only a transient impact on this cat's ventilator dependency because its ventilatory ability did not improve even after its body temperature returned to normal.

Lastly, the potential impact of the cat's acute neurologic signs, specifically its persistently impaired consciousness in the postoperative period and the subsequent development of anisocoria, are worth mentioning because they suggest the presence of brainstem dysfunction. The principle neurons governing arousal and consciousness are located within the reticular activating system in the brainstem, while the afferent and efferent pathways governing pupillary size and responsiveness to light travel through the brainstem for a part of their course.[30,31] The respiratory neurons responsible for establishing the respiratory rhythm and coordinating inputs are also located in the brainstem, in the rostral medulla.[30] However, despite these deficits, there is no evidence of clinical impairment of the cat's respiratory center and the cat maintained an appropriate respiratory rate, rhythm and subjectively adequate respiratory muscle excursions during the SBT. Although the necropsy did not identify a definitive cause for the neurologic signs, cerebral thromboembolism could be considered a possibility, as fibrin thrombi can undergo rapid postmortem dissolution.[32] There was no evidence of neoplasia, hemorrhage or trauma found within the central nervous tissue, grossly or histologically.

Little is reported about cats and the outcomes of MV, but survival rates are uniformly low at 15–20%, and those ventilated for hypoxemia have worse outcomes than those with primary hypoventilation.[33,34] Even less is known about the postoperative morbidity and mortality in cats that require MV following extensive rib resection and chest wall reconstruction. MV is a common short-term intervention following radical chest wall resection in humans.[35] While published information is limited, available studies suggest that postoperative complications are common, but short-term mortality rates are comparatively low (⩽7%).[35–38] A recent publication of 59 human patients with chest wall reconstruction following the resection of 5–10 ribs reported an average of 3.9 ventilator-dependent days, difficulty weaning in 3.3% and a 30-day survival rate of 96.6%.[35]

In the cat in this report, MV was similarly intended to serve as a transient intervention to allow time for strengthening and adaptation of the remaining inspiratory musculature. However, in retrospect, it is unlikely that this approach would ultimately have been successful. Cats and humans exhibit differences in thoracic wall conformation, and large chest wall defects in cats, despite reconstruction, might lack the stability and rigidity necessary to support adequate respiratory mechanics. While additional retrospective studies to evaluate morbidity and mortality following chest wall resection in cats would be beneficial, the small number of published studies that are currently available have reported variable, but generally good, outcomes. In addition to the absolute number of ribs resected, it is possible that other factors may also be important, such as whether the removed portion of the chest wall is in the cranial, middle or caudal thorax, and the percentage of each rib that is removed.

We acknowledge that surgical decision-making played an important role in this cat's outcome which, in retrospect, might have been foreseen. Beyond the number of ribs resected, one should also consider the location and extent of each rib resection. In our case, each rib was resected nearly completely, resulting in a relatively large chest wall defect. In future cases with similar masses, one should consider a more rigid chest wall reconstruction and adopting smaller, 3 cm surgical margins, as described by Muller and Kessler,[4] to reduce the risk of postoperative ventilatory failure. Though the combination of rapid tumor regrowth and financial constraints prompted this owner to elect the radical surgical approach presented here, the risk of development of severe ventilatory compromise necessitating MV should be discussed with pet owners prior to performing radical chest wall resection. In these situations, the pros and cons of alternative management strategies, including smaller surgical margins, radiation therapy and chemotherapy, will form an important part of the decision-making process.

Conclusions

Ventilatory failure is a risk associated with radical chest wall resection in cats. Clinicians should be aware of the possibility of hypoventilation as a potential complication that may require the use of MV postoperatively.

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Ethical approval This work involved the use of non-experimental animals only (including owned or unowned animals and data from prospective or retrospective studies). Established internationally recognized high standards ('best practice') of individual veterinary clinical patient care were followed. Ethical approval from a committee was therefore not specifically required for publication in *JFMS Open Reports*.

Informed consent Informed consent (either verbal or written) was obtained from the owner or legal custodian of all animal(s) described in this work (either experimental or non-experimental animals) for the procedure(s) undertaken (either prospective or retrospective studies). No animals or humans are identifiable within this publication, and therefore additional informed consent for publication was not required.

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References

1 Daly MK, Saba CF, Crochik SS, et al. **Fibrosarcoma adjacent to the site of microchip implantation in a cat.** *J Feline Med Surg* 2008; 10: 202–205.

2 Munday JS, Banyay K, Aberdein D, et al. **Development of an injection site sarcoma shortly after meloxicam injection in an unvaccinated cat.** *J Feline Med Surg* 2011; 13: 988–991.

3 Giudice C, Stefanello D, Sala M, et al. **Feline injection-site sarcoma: recurrence, tumor grading and surgical margin status evaluated using the three-dimensional histologic technique.** *Vet J* 2010; 186: 84–88.

4 Muller N and Kessler M. **Curative-intent radical en bloc resection using a minimum of a 3 cm margin in feline injection-site sarcomas: a retrospective analysis of 131 cases.** *J Feline Med Surg* 2018; 20: 509–519.

5 Zabielska-Koczywas K, Wojtalewicz A and Lechowski R. **Current knowledge on feline injection-site sarcoma treatment.** *Acta Vet Scand* 2017; 59: 47. DOI: 10.1186/s13028-017-0315-y.

6 Phelps HA, Kuntz CA, Milner RJ, et al. **Radical excision with five-centimeter margins for treatment of feline injection-site sarcoma: 91 cases (1998–2002).** *J Am Vet Med Assoc* 2011; 239: 97–106.

7 Hershey AE, Sorenmo KU, Hendrick MJ, et al. **Prognosis for presumed feline vaccine-associated sarcoma after excision: 61 cases (1986–1996).** *J Am Vet Med Assoc* 2000; 216: 58–61.

8 Davidson EB, Gregory CR and Kass PH. **Surgical excision of soft tissue fibrosarcomas in cats.** *Vet Surg* 1997; 26: 265–269.

9 Lidbetter DA, Williams FA, Krahwinkel DJ, et al. **Radical lateral body-wall resection for fibrosarcoma with reconstruction using polypropylene mesh and a caudal superficial epigastric axial pattern flap: a prospective clinical study of the technique and results in 6 cats.** *Vet Surg* 2002; 31: 57–64.

10 Matthiesen DT, Clark GN, Orsher RJ, et al. **En bloc resection of primary rib tumors in 40 dogs.** *Vet Surg* 1992; 21: 201–204.

11 Foroulis CN, Kieontas AD, Tagarakis G, et al. **Massive chest wall resection and reconstruction for malignant disease.** *Onco Targets Ther* 2016; 9: 2349–2358.

12 Mansour KA, Thourani VH, Losken A, et al. **Chest wall resections and reconstruction: a 25-year experience.** *Ann Thorac Surg* 2002; 73: 1720–1726.

13 Weyant MJ, Bains MS, Venkatraman E, et al. **Results of chest wall resection and reconstruction with and without rigid prosthesis.** *Ann Thorac Surg* 2006; 81: 279–285.

14 Scarneccia E, Liparulo V, Capozzi R, et al. **Chest wall resection and reconstruction for tumors: analysis of oncological and functional outcome.** *J Thorac Dis* 2018; 10: S1855–S1863.

15 Liptak JM, Dernell WS, Rizzo SA, et al. **Reconstruction of chest wall defects after rib tumor resection: a comparison of autogenous, prosthetic, and composite techniques in 44 dogs.** *Vet Surg* 2008; 37: 479–487.

16 Bowman KLT, Birchard SJ and Bright RM. **Complications associated with the implantation of polypropylene mesh in dogs and cats: a retrospective study in 21 cases (1982–1996).** *J Am Anim Hosp Assoc* 1998; 34: 225–233.

17 Davis KM, Hardie EM, Martin FR, et al. **Correlation between perioperative factors and successful outcome in fibrosarcoma resection in cats.** *Vet Rec* 2007; 161: 199–200.

18 Liptak JM, Kamstock DA, Dernell WS, et al. **Oncologic outcome after curative-intent treatment in 39 dogs with primary chest wall tumors (1992–2005).** *Vet Surg* 2008; 37: 488–496.

19 Cloutier MM. **Mechanical properties of the lung and chest wall.** In: Cloutier MM (ed). Respiratory physiology. 2nd ed. Philadelphia, PA: Elsevier, 2019, pp 15–28.

20 West JB. **Mechanics of breathing.** In: West JB (ed). Respiratory physiology: the essentials. 9th ed. Baltimore, MD: Wolters Kluwer Medical, 2012, pp 95–124.

21 Cappello M and Troyer A. **On the respiratory function of the ribs.** *J Appl Physiol* 2002; 92: 1642–1646.

22 Vassilakopoulos T and Petrof BJ. **Ventilator-induced diaphragmatic dysfunction.** *Am J Respir Crit Care Med* 2004; 169: 336–341.

23 Chang AT, Boots RJ, Brown MG, et al. **Reduced inspiratory muscle endurance following successful weaning from prolonged mechanical ventilation.** *Chest* 2005; 128: 555–559.

24 Vivier E, Roussey A, Doroszewski F, et al. **Atrophy of diaphragm and pectoral muscles in critically ill patients.** *Anesthesiology* 2019; 131: 569–579.

25 Sassoon CH, Caiozzo VJ, Manka A, et al. **Altered diaphragm contractile properties with controlled mechanical ventilation.** *J App Physiol* 2002; 92: 2585–2595.

26 Bernard N, Matecki S, Py G, et al. **Effects of prolonged mechanical ventilation on respiratory muscle ultrastructure and mitochondrial respiration in rabbits.** *Intensive Care Med* 2003; 29: 111–118.

27 Formenti P, Umbrello M, Dres M, et al. **Ultrasonographic assessment of parasternal intercostal muscles during mechanical ventilation.** *Ann Intensive Care* 2020; 10: 120. DOI: 10.1186/s13613-020-00735-y.

28 Moodie L, Reeve J and Elkins M. **Inspiratory muscle training increases inspiratory muscle strength in patients weaning from mechanical ventilation: a systematic review.** *J Physiother* 2011; 57: 213–221.

29 Grimm KA. **Perioperative thermoregulation and heat balance.** In: Grimm KA, Lamont LA, Tranquilli WJ, et al (eds). Veterinary anesthesia and analgesia. 5th ed. Ames, IA: John Wiley, 2015, pp 377–378.

30 Lumb A and Thomas C. **Control of breathing.** In: Lumb A (ed). Nunn's applied respiratory physiology. 9th ed. Philadelphia, PA: Elsevier, 2021, pp 42–58.

31 Dewey CW. **Lesion localization: functional and dysfunctional neuroanatomy.** In: Dewey CW and da Costa RC (eds). Practical guide to canine and feline neurology. 3rd ed. Ames, IA: John Wiley, 2016, pp 32–37.

32 Moser KM, Guisan M, Bartimmo EE, et al. **In vivo and post mortem dissolution rats of pulmonary emboli and venous thrombi in the dog.** *Circulation* 1973; 48: 170–178.

33 Lee JA, Drobatz KJ, Koch MW, et al. **Indications for and outcome of positive-pressure ventilation in cats: 53 cases (1993–2002).** *J Am Vet Med Assoc* 2005; 226: 924–931.

34 Hopper K, Haskins SC, Kass PH, et al. **Indications, management, and outcome of long-term positive-pressure ventilation in dogs and cats: 148 cases (1990–2001).** *J Am Vet Med Assoc* 2007; 230: 64–75.

35 Corkum JP, Garvey PB, Baumann DP, et al. **Reconstruction of massive chest wall defects: a 20-year experience.** *J Plast Reconstr Aesthet Surg* 2020; 73: 1091–1098.

36 Losken A, Thourani VH, Carlson GW, et al. **A reconstructive algorithm for plastic surgery following extensive chest wall resection.** *Br J Plast Surg* 2004; 57: 295–302.

37 Ahmad SB, Hoellwarth J, Christie N, et al. **Radical resection of a giant rib osteosarcoma with complex chest wall reconstruction.** *Int J Surg Case Rep* 2019; 62: 17–20.

38 Scarnecchia E, Liparulo V, Pica A, et al. **Multidisciplinary approach to chest wall resection and reconstruction for chest wall tumors, a single center experience.** *J Thorac Dis* 2017; 9: 5093–5100.