COMPANION OR PET ANIMALS

Multiple segment total en bloc vertebrectomy and chest wall resection in a dog with an invasive myxosarcoma

Julius M Liptak,[1] Stan Veytsman,[1] Shanna Kerr,[1] Jan Klasen[2]

[1]VCA Canada - Alta Vista Animal Hospital, Ottawa, Ontario, Canada
[2]Tierklinik Germersheim, Germersheim, Germany

Correspondence to
Dr Julius M Liptak;
animalcancersurgeon@icloud.com

Received 28 November 2019
Revised 17 February 2020
Accepted 18 March 2020

SUMMARY

A 9.5-year-old, 22.6 kg, castrated male mixed breed dog was diagnosed with a paravertebral myxosarcoma invading into the T9–T11 vertebrae and dorsal left-sided thoracic wall. A total multisegment vertebrectomy of T9–T12 and chest wall resection of the left 8th–12th ribs were performed to resect the tumour en bloc. A patient-specific, three-dimensional implant was designed and printed to reconstruct the defect in the vertebral column following resection of the tumour. This implant was supplemented with four 2.7 mm string-of-pearl plates. The chest wall defect was reconstructed with a latissimus dorsi muscle flap. Postoperative complications included neurological deterioration, and necrosis of the latissimus dorsi muscle flap resulting in marked pneumothorax and cardiorespiratory arrest 17 days postoperatively.

BACKGROUND

The management of vertebral tumours is challenging in both human and veterinary medicine. The majority of published studies in veterinary medicine describe cytoreductive surgery for the management of primary vertebral tumours, such as decompressive surgery or partial vertebrectomy, with or without adjuvant radiation therapy or chemotherapy.[1–4] The vast majority of these cases fail because of either local disease progression or local tumour recurrence. In humans, the type of treatment and aggressiveness of treatment depends on the tumour type and the circumferential extent of vertebral involvement, as defined by the Weinstein–Boriani–Biagini vertebral tumour staging system.[5] For malignant vertebral tumours, surgery is the preferred modality for treatment of the local tumour. The aggressiveness of surgery has evolved from a cytoreductive approach, such as decompressive surgery or partial vertebrectomy, to en bloc vertebrectomy (or spondylectomy). En bloc vertebrectomy is defined as complete resection of all affected vertebra(e), including paraspinal muscles and ligaments, and adjacent anatomic barriers, without violation of the tumour capsule.[6–10] Multiple studies have shown a significantly improved outcome in patients treated with en bloc vertebrectomy in comparison to less aggressive surgical techniques.[7 11–19]

Our objectives were to describe surgical procedure and postoperative outcome following multisegment en bloc vertebrectomy and chest wall resection in a dog with an invasive myxosarcoma, and discuss the role of total en bloc vertebrectomy in the management of dogs with tumours involving the vertebra.

CASE PRESENTATION

A 9.5-year-old, 22.6 kg, castrated male mixed breed dog presented with a 2-month history of difficulty jumping and pain while posturing to defecate, and a palpable 4 cm subcutaneous mass on the left dorsolateral aspect of the thoracolumbar region. An MRI showed a left dorsal paravertebral soft tissue mass extending into the proximal aspect of the 12th rib, left dorsolateral lamina and left lateral T12 vertebral body. On physical and neurologic exam, the dog had a palpably painful left dorsal paravertebral mass, extending from T11 to T13, with mild conscious proprioceptive deficits in both pelvic limbs, but no evidence of either reflex abnormalities or ataxia.

INVESTIGATIONS

The dog was sedated with dexmedetomidine (13.4 mcg/kg intravenously) and a pre-contrast and post-contrast CT scan was performed followed by an 8 mm punch biopsy of the mass. The CT scan revealed a 6.9 cm by 6.0 cm by 5.3 cm lobulated soft tissue mass (figure 1). The soft tissue component of the mass extended into the left paraspinal muscles from T9 to T13, and ventrally into the thoracic cavity to cause an extrapleural mass effect at the medial aspect of the left diaphragmatic crus. The mass invaded medially with lysis of the T9 dorsal lamina and spinous process, T10 dorsal lamina, spinous process, left pedicle, left aspect of the vertebral body, and costal fovea, and the T11 left pedicle, left aspect of the vertebral body, costal fovea and rib head. This invasion into the spinal canal caused marked left dorsolateral spinal cord compression from the caudal end plate of T9 to the caudal end plate of T10. In addition, there were multiple, ill-defined, contrast-enhancing hepatic nodules. There was no evidence of pulmonary metastasis. The mass was histologically diagnosed as a grade I myxosarcoma, with one mitotic figure per 10 high-power fields (HPFs) and mildly pleomorphic nuclei.

TREATMENT

Options discussed with the owner included ultrasound-guided aspirates of one or more of the liver lesions, referral for either stereotactic or intensity-modulated radiation therapy, surgical decompression or total en bloc vertebrectomy. The advantages, disadvantages and potential complications of each approach were discussed; this

To cite: Liptak JM, Veytsman S, Kerr S, *et al*. *Vet Rec Case Rep* Published Online First: [*please include* Day Month Year]. doi:10.1136/vetreccr-2019-001033

Figure 1 Preoperative contrast-enhanced CT scan showing a large, multilobulated soft tissue mass invading into the dorsal spinous process, dorsal lamina, left pedicle and left aspect of the vertebral body of t10.

included that total en bloc vertebrectomy had not previously been reported in veterinary medicine, to the best of the authors' knowledge, and that pelvic limb paralysis with urinary and faecal incontinence were possible consequences following total en bloc vertebrectomy. The owner elected to proceed with total en bloc vertebrectomy, without preoperative aspirates of the liver lesions, because the aim of the owner was curative-intent treatment with the knowledge that paralysed dogs can be managed with a good quality of life.[20 21]

To reconstruct the vertebral column after total en bloc vertebrectomy, a patient-specific implant was designed. The DICOM files of the CT scan were sent electronically to one of the authors (JK) for computer-aided design and manufacture (Additive Design in Surgical Solutions (ADEISS) Centre, London, ON, Canada) of a customised, three-dimensional (3D)-printed titanium implant. The implant had a clam-shell design to allow insertion of one half of the implant into the vertebral column defect to maintain spatial alignment prior to repositioning the dog and completing the remainder of the resection. The second half of the implant would then be inserted into the contralateral defect and connected to the first half of the implant with machined screws. In addition, each half of the implant had two integrated plates with four non-locking 2.7 mm screw holes to secure the implant to the dorsolateral and ventral components of the two vertebrae cranial (T7 and T8) and caudal (T13 and L1) to the T9–T12 multisegment total en bloc vertebrectomy (figure 2A,B). While T12 was not involved in the disease process at the time of the CT scan, en bloc resection of T12 with T9–T11 was planned because of the growth rate of the tumour and the proximity of the tumour to the cranial aspect of T12. Due to the complexity of the design and the design process, the time period between submission of the CT and delivery of the implant was 42 days.

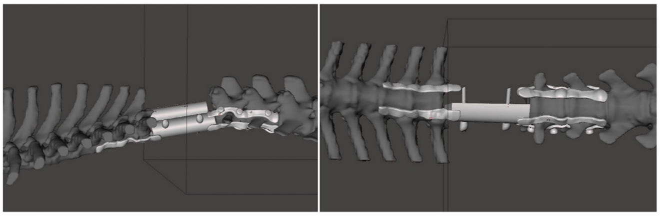

Figure 2 Lateral (A) and ventral (B) views of the patient-specific prosthesis for vertebral column reconstruction showing the clam shell design of the prosthesis and ventral and dorsolateral integrated plates to secure the prosthesis to the adjacent cranial and caudal vertebral bodies.

Preoperative complete blood count and serum biochemistry abnormalities included increases in alanine transferase (128 U/L; reference range, 12–118 U/L) and alkaline phosphatase (627 U/L; reference range, 5–131 U/L). Based on these results, his underlying diseases, and the findings on preoperative exam, the dog was classified as an American Society of Anesthesiologists (ASA) II anaesthetic risk. The dog was premedicated with 2.0 mg/kg lidocaine intravenously and 1.0 mg/kg maropitant citrate intravenously 1 hour prior to induction. Constant rate infusions (CRI) of remifentanil (6.0 mcg/kg/hour*), lidocaine (0.9 mg/kg/hour) and ketamine (0.3 mg/kg/hour) were started prior to surgery. Flow-by oxygen was provided via a facemask. The patient was then bolused with 5.0 mcg/kg remifentanil intravenously and 0.5 mg/kg ketamine intravenously. Intravenously, alfaxan at 2.0 mg/kg was titrated until the patient was able to be intubated. The patient was placed on an F-circuit anaesthetic machine with a 2 L rebreathing bag with 100% oxygen at 1.5 L/min and initially maintained at 1.5% to 2.0% isoflurane. The remifentanil CRI was increased to 12.0 mcg/kg/hour. The patient was maintained on intravenous Plasma-lyte A with total intravenous fluids delivered at a rate of 5.0 mL/kg/hour. An arterial line was placed in the right dorsal pedal artery for invasive blood pressure monitoring and blood analysis intraoperatively. The dog was placed on a mechanical ventilator. Patient monitoring equipment included electrocardiography, pulse oximetry, capnography, oesophageal temperature, and invasive and non-invasive blood pressures. The patient was given intravenously 22.0 mg/kg cefazolin slowly 30 min prior to surgery and this was repeated every 90 min perioperatively.

The dog was positioned in sternal recumbency and aseptically prepared. A dorsal midline thoracolumbar incision was made extending from the mid-thoracic to the mid-lumbar region. The thoracolumbar fascia was incised on the right side from T6 to L2. The multifidus muscles were reflected off the dorsal spinous processes and articular facets from T6 to L2. A hemilaminectomy, extending from the dorsal spinous process to the ventral floor of the vertebral canal, was performed from T8 to T13 with a Hall's air drill, curettes and Kerrison rongeurs (figure 3). The aim of this part of the surgery was to expose the spinal cord and the ventral aspect of the spinal canal to allow for a paramedian hemivertebral osteotomy later in the surgery.

The dog was then rolled into a right lateral recumbent position. A skin incision was performed over the tumour, and the skin reflected. The mass was excised with 2 cm lateral margins in the subcutaneous tissue and muscles. Incisions were made along the ventral, caudal and dorsal borders of the latissimus dorsi muscle, and this muscle flap was raised, and protected in moistened laparotomy sponges, for later use to reconstruct the chest wall defect. The caudodorsal portion of the latissimus dorsi muscle flap was resected to remove the biopsy tract. An incision was made along the caudal aspect of the 12th rib to expose the abdominal cavity and diaphragm. Multiple liver nodules were noted. In-house cytologic assessment of these lesions was not available. The possibility that these lesions represented metastatic disease was discussed intraoperatively with the owner; the owner elected to continue with surgery. Three of these liver lesions were biopsied with a 5 mm punch biopsy.

An incision was made along the left diaphragmatic crus to expose the caudal thoracic cavity, ventral aspect of the thoracolumbar vertebrae and ventral aspect of the tumour along the vertebral body (figure 4). The left 8th–12th ribs were

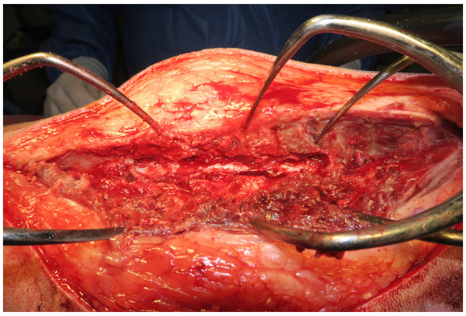

Figure 3 Right-sided hemilaminectomy from T8 to T13. The aim of this part of the surgery was to expose the spinal cord and the ventral aspect of the spinal canal to allow for a later paramedian hemivertebral osteotomy.

ostectomised at the mid-aspect of the ribs with bone cutters and the intercostal muscles were transected transversely at this level. A seventh intercostal incision was then performed from the level of the eighth rib ostectomy proximally.

The aorta was protected via the diaphragmatic approach with a malleable retractor. Returning to the right side of the dog, the spinal cord was then gently retracted towards the midline with malleable retractors to expose the floor of the vertebral canal. Rhizotomy of the right T9–T12 nerve roots was performed within 10 mm of the spinal cord and bleeding from spinal vessels was controlled with cautery. An oscillating saw was used to perform an osteotomy of the T9–T12 vertebral bodies along the right paramedian aspect of these vertebral bodies (figure 5). The T8–T9 and T12–T13 intervertebral disks were incised. Two 1″ Penrose drains were placed circumferentially around the spinal cord through the cranial and caudal aspects of the hemilaminectomy site (figure 6A). With the spinal cord stabilised with Penrose drains, the paravertebral mass, with the T9–T12 vertebral segments left of the right paramedian vertebral osteotomy and proximal half of the 8th–12th ribs, was removed en bloc by gently manipulating the resected tumour so that the spinal cord slipped through the hemilaminectomy site (figure 6B). Rhizotomy of the left T9–T12 nerve roots was performed when these nerve roots became visible during manipulation of the tumour away from the stabilised spinal cord segment.

The left side of the patient-specific, 3D-printed titanium implant was inserted into the vertebral defect (figure 7). The surgical plan was modified following delivery of the implant; the integrated non-locking plates were malleable and we were concerned that these would be inadequate for long-term stabilisation of the vertebral column. As a result, the implant with its integrated plates was secured with stacked contoured 20-hole 2.7 mm string-of-pearls (SOP) plates ventrally and dorsolaterally with two 2.7 mm screws cranially and caudally in each of the T7, T8, T13 and L1 vertebral bodies.

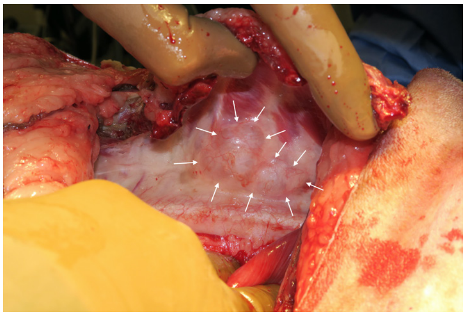

Figure 4 Following isolation of the caudal left chest wall (ribs 8–12), the chest wall was reflected dorsally to expose the ventral aspect of the tumour (arrows) adjacent to the aorta.

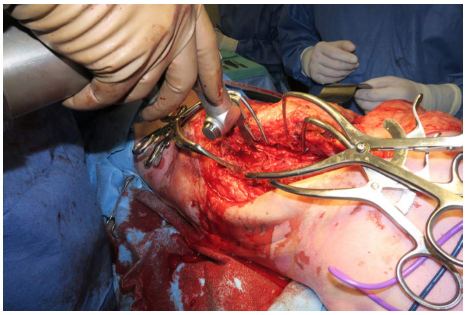

Figure 5 An oscillating saw was used to osteotomised the vertebral bodies of T9–T12 through the ventral aspect of the vertebral canal via the T8–T13 hemilaminectomy.

The dog was repositioned into a left oblique sternal position. The right side of the T8–T9 and T12–T13 intervertebral disks was incised and the rib heads were ostectomised with bone cutters, which allowed the residual right side of the vertebral bodies of T9–T12 to be removed. The right side of the patient-specific, 3D-printed implant was inserted into the vertebral defect. The dorsolateral integrated plate was secured with a stacked 20-hole contoured 2.7 mm SOP plate with two 2.7 mm screws per plate in each of the T7, T8, T13 and L1 vertebral bodies. The intention was to secure the two halves of the implant together with machined screws, but this was not possible intraoperatively because of interference of the paravertebral soft tissues.

The dog was repositioned into right lateral recumbency. The right ventral integrated implant plate could not be secured to the vertebral body because of poor fit, but a 20-hole 2.7 mm SOP plate was used to bridge the defect on the right ventral aspect of the vertebral bodies of T7, T8, T13 and L1 (figures 8 and 9). The surgery site was lavaged with warmed sterile isotonic saline, avoiding direct lavage of the spinal cord. A 14 FG Miele thoracostomy tube was inserted into the left hemithorax. The dorsal and caudal aspects of the latissimus dorsi muscle were sutured to right epaxial muscles with 0 polydioxanone (PDS) cruciate suture pattern. The diaphragm was advanced cranially and sutured to the ventral aspect of the latissimus dorsi muscle flap and the dorsal aspect of the 8th–12th ribs with 0 PDS cruciate suture pattern. The abdominal wall defect was closed with doubled over prosthetic polypropylene mesh (PROLENE Mesh, Ethicon, Johnson & Johnson) because reconstruction of this defect was not possible with the latissimus dorsi muscle flap, which was sutured to the abdominal wall and latissimus dorsi muscle flap with 0 PDS simple continuous suture patterns. A 7″

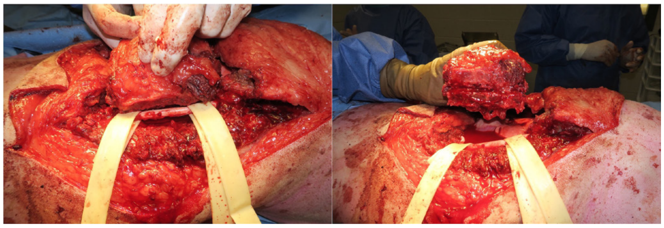

Figure 6 Following completion of the multisegment vertebral osteotomy, A. 1″ penrose drains were placed around the spinal cord and B. the T9–T12 vertebral segment and left chest wall were gently rotated away from the spinal cord.

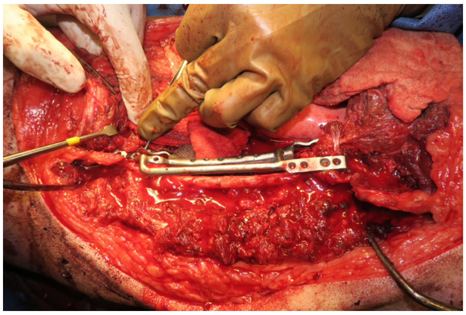

Figure 7 To maintain spatial alignment of the vertebral column prior to completion of the en bloc vertebrectomy, the left half of the patient-specific prosthesis was inserted into the vertebral defect and secured to the adjacent cranial and caudal vertebral bodies with the screws through the integrated prosthesis plates.

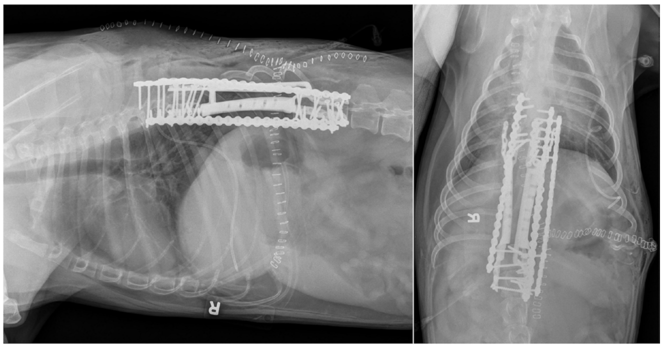

Figure 9 Immediate postoperative lateral (A) and ventrodorsal (B) radiographs showing multisegment en bloc vertebrectomy of T9–T12 and reconstruction with a patient-specific prosthesis and three 2.7 mm SOP plates.SOP: string-of-pearls.

pain soaker catheter was inserted through a separate stab incision. The subcutaneous tissue and skin were closed routinely. The surgical margins of the resected tumour were inked and both the mass and liver biopsies were submitted for histopathology. The tumour was confirmed as a grade I myxosarcoma with complete histologic excision (closest histologic tumour-free margin was 15 mm) and rare mitotic figures, and the liver lesions were diagnosed as nodular hyperplasia.

During surgery, the dog was initially hypertensive (invasive blood pressure measurements: 160–194 mm Hg systolic, 82–95 mm Hg mean) with a sinus bradycardia (40–48 beats/min). The lidocaine CRI was increased to 10.0 mcg/kg/min for the first hour of surgery then adjusted between 3.0 and 5.0 mcg/kg/min for the remainder of surgery. Remifentanil was adjusted between 18.0–30.0 mcg/kg/hour and ketamine remained at 0.6 mg/kg/hour throughout surgery. Between 2 and 4 hours of surgery, systolic and mean blood pressures decreased steadily to 118 and 41 mm Hg, respectively, with an increase in heart rate (60–77 beats/min). There was minimal response to two 10.0 mL/kg crystalloid fluid boluses administered over 15 min. Two colloid (Voluven) boluses, administered at 5.0 mL/kg over 15 min and decreased isoflurane (1.25% to 0.8%), resolved the hypotension. During the fifth hour of surgery, blood loss resulted in further hypotension. Dopamine was started at 5.0 mcg/kg/min intravenously, but this was discontinued because of an arrhythmia. A 250 mL bag of cross-matched, packed red blood cells was transfused over 2 hours at 5.5 mL/kg/hour after an initial test dose of 1.0 mL/kg/hour over 15 min. Hypotension continued to be an issue until the finish of the 7.5-hour surgery; this was managed with one 10.0 mL/kg crystalloid bolus intravenously and three 5.0 mL/kg colloid boluses over 15 min each, and a second 250 mL packed red blood cell transfusion.

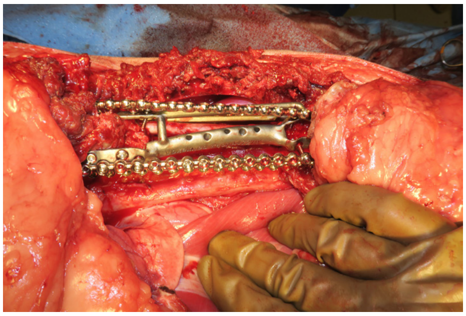

Figure 8 Following completion of the multisegment vertebrectomy, both halves of the prosthesis were used to reconstruct the vertebral column and this was secured to T7 and T8 cranially and T13 and L1 caudally with a combination of integrated prosthesis plates and supplemental 2.7 mm SOP plates ventrally and dorsolaterally. SOP: string-of-pearls.

The dog was recovered in our critical care unit. Hypotension resolved postoperatively, although urine production was initially <1.0 mL/kg/hour and his intravenous fluid rate was increased to 60.0 mL/kg/day. Neurologically, the dog was paraplegic with no deep pain sensation in the pelvic limbs and a Schiff-Sherrington posture of the thoracic limbs. A cutaneous trunci reflex was present to T7 on the left side and T9 on the right side. Passive range of motion was started and he was rotated every 6 hours to prevent decubital ulcer formation and pulmonary atelectasis. The remifentanil–ketamine–lidocaine CRI was weaned down over a 4-day period starting on his first postoperative day and stopped on his fifth postoperative day; analgesia was continued with oral deracoxib (1.6 mg/kg), tramadol (3.3 mg/kg) and gabapentin (13.3 mg/kg).

OUTCOME AND FOLLOW-UP

Neurologically, the dog remained paraplegic with an absence of deep pain in both pelvic limbs. Cutaneous trunci reflexes deteriorated on day 3 and were absent on the left side and was present to T8 on the right side; however, within 24 hours, cutaneous trunci reflexes improved and were present to T7 on the left side and to T9 on the right side. A postoperative CT scan was performed on day 4. Two screws in T6 and one screw in T7 coursed through the dorsolateral aspect of the vertebral canal. The proximity of these screws to the spinal cord could not be evaluated because of metallic artefact caused by the patient-specific implant, SOP plates and screws. Multiple thoracic radiographs were taken over the following 13 days; there was no evidence of implant-associated complications. The dog improved to ambulatory status in the thoracic limbs by day 14.

On day 3, the dog developed tachypnoea. Orthogonal thoracic radiographs showed mild bilateral pleural effusion. Thoracocentesis was performed via the thoracostomy tube and the pleural fluid was serosanguineous (packed cell volume (PCV), 8%; total solids (TS), 0.2 g/L). Peripheral PCV and TS were stable at 28% and 3.0 g/L, respectively. A coagulation profile was within the normal reference ranges (prothrombin 8.5 s, reference range 6.0–12.0 s; partial thromboplastin time 17.1 s, reference range 10.0–25.0 s). Due to continued dyspnoea and tachypnoea, thoracocentesis was repeated bilaterally on day 4 (320 mL serosanguineous pleural fluid) and day 5 (320 mL serosanguineous pleural fluid, PCV 5%). Mild-to-moderate pleural effusion persisted on day 6, but thoracocentesis was not required because the tachypnoea was considered mild. The dog was stable for 3 days, but then developed acute dyspnoea on day 9; dyspnoea resolved following left-sided thoracocentesis. The pleural fluid was submitted for culture; there was no bacterial growth after 72 hours. The dog did not have dyspnoea or tachypnoea for a further 7 days.

Incisional healing was uneventful until day 6 when mild skin necrosis was noted at the junction of the T-shaped skin closure. This did not require revision initially and healed by second intention, but this area reopened at day 15. The area was aseptically prepared and closed with skin staples. On day 16, a hissing noise was noted at the incisional junction during manual expression of his urinary bladder. Orthogonal thoracic radiographs were taken and there was no evidence of pneumothorax. The same finding was noted on day 17, but the dog also became acutely dyspnoeic and tachypnoeic. Thoracocentesis was performed with air being aspirated continuously from the left hemithorax (>1800 mL). The dog arrested at this time. He was intubated and closed cardiopulmonary resuscitation was initiated while the surgical area was aseptically prepared and explored. The subcutaneous tissue and latissimus dorsi muscle flap were necrotic. The dog did not respond to resuscitative efforts and, combined with the emergent surgical findings, further cardiopulmonary resuscitation was stopped 15 min after respiratory arrest was first noted.

A necropsy was performed. There was marked, generalised myonecrosis of the latissimus dorsi muscle flap with regeneration, mineralisation and fibrosis; as well as marked, generalised myonecrosis of the epaxial muscles with fibrosis. Marked myelomalacia was noted from T9 to T12, with mild-to-moderate ascending and descending axonal degeneration to T2–T4 and L2, respectively.

DISCUSSION

Total en bloc vertebrectomy was elected by the owner of this dog because of the curative-intent potential of this procedure compared with the more commonly described palliative approaches in veterinary medicine, such as decompressive surgery or partial vertebrectomy, with or without adjuvant radiation therapy or chemotherapy.[1–4] The vast majority of these cases fail because of either local disease progression or local tumour recurrence. In one study, 20 dogs with primary or metastatic vertebral tumours were treated with surgery alone (n=4), surgery and chemotherapy (2), surgery, radiation, and chemotherapy (8), or radiation therapy and chemotherapy (6). Overall, 15 dogs were euthanised because of local failure, but the local failure rates for each group were not reported.[1] In a study of 26 cats with non-lymphoid vertebral and spinal cord tumours treated with cytoreductive surgery, all four cats with primary vertebral tumours were euthanised because of local tumour recurrence.[2] Two of three dogs with surgically treated primary vertebral chondrosarcoma were euthanised because of local failure.[3] Finally, in one study of 22 dogs with primary vertebral osteosarcoma treated with surgery alone or in combination with various adjuvant modalities, all dogs surviving the initial postoperative period were euthanised because of local failure.[4] Based on these retrospective clinical studies, cytoreductive surgical techniques result in incomplete microscopic or macroscopic resection and a high local failure rate with only a short-term palliation of neurologic signs. As the authors of two of these studies stated,[1 2] better treatment options should be investigated for the treatment of primary bone tumours in cats and dogs.

In humans, the type of treatment and aggressiveness of treatment depends on the tumour type and the circumferential extent of vertebral involvement, as defined by the Weinstein–Boriani–Biagini vertebral tumour staging system.[5] The aggressiveness of surgery has evolved from a cytoreductive approach, such as decompressive surgery or partial vertebrectomy, to en bloc vertebrectomy. Total vertebrectomy has been reported in a dog with a primary fibrosarcoma of the fifth lumbar vertebra,[22] a cat with a primary giant cell osteosarcoma of the first lumbar vertebra[23] and a dog with a chronic traumatic luxation of the third and fourth lumbar vertebrae.[24] In both cases involving a primary vertebral tumour, total vertebrectomy was performed after cytoreductive surgery failed, either because of pathologic fracture[22] or local tumour recurrence,[23] and the total vertebrectomy was performed piecemeal intralesionally rather than en bloc. Piecemeal intralesional total vertebrectomies are defined as palliative because oncologic principles are compromised.[12 25] In one series of 56 people with primary vertebral tumours treated initially with an intralesional approach and then subsequently with en bloc vertebrectomy, the margins obtained were wide, marginal and intralesional in 16%, 50% and 34%, respectively[26]; however, there was no correlation between margins, local recurrence and survival because the initial intralesional approach and resultant contamination compromised patient prognosis and this could not be salvaged with more aggressive surgery.

En bloc vertebrectomy is defined as complete resection of all affected vertebra(e), including paraspinal muscles and ligaments, and adjacent anatomic barriers, without violation of the tumour capsule according to the Enneking surgical margin classification for the management of musculoskeletal tumours.[6–10] As a result, there is complete loss of vertebral continuity and stability at the resection site and circumferential reconstruction is required to reestablish vertebral integrity and stability. The technique used to stabilise the vertebral column should account for the expected long survival time as well as the effects of adjuvant treatment options, such as chemotherapy and radiation therapy.[27] These reconstruction techniques are well established in humans and typically involve posterior reconstruction with pedicle screws and rods, and anterior reconstruction with a titanium cage.[25 27] In one series, the overall rate of construct failure was 14%, but only 4.1% required surgical revision.[27] We elected to reconstruct the vertebral column defect with a patient-specific, 3D-printed implant because of a lack of experience and availability of the appropriately sized instruments used for reconstruction in human patients, the length of the vertebral defect (four vertebrae), and the inherent theoretical advantages of patient-specific, 3D-printed implants. These advantages include superior anatomic fit, reduced surgical time and decreased risk of iatrogenic damage to the spinal cord with preplanning the direction of the screws.[28–30] Despite these potential advantages, we experienced several problems with the iteration of the implant used in our patient. First, the anatomic fit was not as ideal as we have experienced for other anatomic regions where we have used patient-specific, 3D-printed implants for oncologic reconstructions, such as the mandible, maxilla, skull and limbs. The paravertebral soft tissues prevented an intimately contoured fit of the implant, especially when the second side of the clam-shell designed implant was attempted to be fixed to the first side of the implant. While we were initially satisfied with the length of the integrated implant plates, the length and malleability of these seemed inadequate when the final iteration was printed. As a result, we chose to supplement the implant with four SOP plates, two dorsolaterally and two ventrolaterally, to improve the stability of the vertebral column reconstruction. This decision was supported by the results of one study where posterior fixation was too short and a lack of anterior support resulted in a significantly increased risk of complications.[27] However, in our case, engaging both the SOP plate hole and the implant plate hole with a single screw limited our ability to direct the screw and avoid placement of screws within the vertebral canal. In future cases, separate reconstruction of the ventral and dorsal components of the vertebral column would be less complicated and less prone to the complications experienced in the case described herein. Options for reconstruction of the ventral component include a titanium cage, as described in people,[25 27] or a patient-specific, 3D-printed titanium spacer, which could be designed to allow modular attachment of an accompanying plate, similar to what is used for endoimplant-based limb-sparing surgery in dogs.[31–33] Locking compression plates and a composite of positive-profile pins and polymethylmethacrylate (PMMA) have been reported for stabilisation of the thoracolumbar region in dogs,[34 35] with the latter being stiffer biomechanically than locking plates.[35] A lateral approach is preferred for placement of positive-profile pins because of greater bone purchase and less risk of iatrogenic trauma to the aorta, but 19% of pins placed through a lateral approach in the lumbar vertebral column entered the vertebral canal.[36] A canine screw and rod fixation system, similar to what is typically used for posterior stabilisation in people, has been biomechanically tested and found to be biomechanically superior to a composite of screws and PMMA.[37] The use of a screw and rod fixation system may be the preferred method of dorsal fixation based on these results, following clinical validation of the system, and experience in people.

The combination of en bloc vertebrectomy and chest wall resection has been reported in people with Pancoast tumour (squamous cell carcinoma of the right lung with invasion into one or more of the second to fourth thoracic vertebrae).[38–47] Similar to en bloc vertebrectomy for primary vertebral tumours, the combination of en bloc resection and chest wall resection for compartmental wide resections results in high complete histologic excision rates (88%) and significantly better outcomes than people with incomplete histologic excision.[43] The most challenging aspect of combined chest wall resections and en bloc vertebrectomies is reconstruction of the chest wall because of the lack of an anchor point dorsally.[44 47–52]

As expected for such aggressive and challenging procedures, whether a total en vertebrectomy or total en vertebrectomy combined with chest wall resection, there is an inherent risk of intraoperative and postoperative complications. Even in high-volume practices, the complication rate following total en bloc vertebrectomy can be high. In one study of 216 patients with 220 total en bloc vertebrectomies, 153 complications were noted in 100 patients (46.3%) and seven patients died as a result of their complications (4.6%).[27] Complications rates are significantly higher in patients with multisegment vertebrectomies, patients treated with a combined approach and patients treated with either neoadjuvant chemotherapy or radiation therapy.[27] The dog described herein had a multisegment (four vertebrae) resection through a combined bilateral approach. The most significant complication in our patient was associated with reconstruction of the chest wall defect with an autogenous latissimus dorsi muscle flap. An autogenous muscle flap was used because of the concern of a surgical site infection with prosthetic mesh, especially after an anaesthesia time of greater than 8 hours.[53] However, in our patient, necrosis of a latissimus dorsi muscle flap was presumably the cause of the initial non-haemorrhagic and non-septic pleural effusion loss, and ultimately resulted in loss of chest wall integrity, marked pneumothorax and cardiorespiratory arrest. Necrosis of the latissimus dorsi muscle flap has previously been reported following chest wall resection in a dog,[54] and this has also been observed following use of the latissimus dorsi muscle flap for cardiac assist in dogs with dilated cardiomyopathy. As a result of this observation, the use of a latissimus dorsi myocutaneous flap was reported for chest wall reconstruction in five dogs following chest wall resection for primary rib chondrosarcomas[55]; there was 100% survival in all flaps, possibly due to improved muscle perfusion because of preservation of choke anastomoses between the latissimus dorsi muscle and overlying skin. Muscle flaps that are dependent on choked vessels for survival in people, such as the pedicled transverse rectus abdominis musculocutaneous flap, have increased risk of partial and total flap necrosis.[56] Other contributing factors to necrosis of the latissimus dorsi muscle flap in the present case include surgical time and tension on the flap, which results in hypoxia and ischaemia.[57] In future cases, consideration should be given to using prosthetic mesh alone to reduce surgical time, a composite of a latissimus dorsi muscle flap and prosthetic mesh so that there are two supplementary reconstruction techniques in case one fails, or a latissimus dorsi myocutaneous flap, with or without additional prosthetic mesh, to improve perfusion of the latissimus dorsi muscle. Despite the risk of complications with total en bloc vertebrectomies with experienced surgeons in high-volume centres, in one meta-analysis, the postoperative complication rate was greater in patients treated with intralesional resections (36.4%) compared with patients treated with en bloc vertebrectomies (11.1%)[13]; so a less aggressive resection has minimal benefits with a higher complication rate and higher risk of local tumour recurrence.

Multiple studies have shown a significantly improved outcome in patients treated with en bloc vertebrectomy in comparison to less aggressive surgical techniques,[7 11–19] even if histologic margins are incomplete.[7 12 16] In one multicentre cohort study investigating the Enneking classification of surgical margins for resection of musculoskeletal tumours in the management of primary vertebral tumours,[19] the local recurrence rate was significantly higher in patients in the Enneking inappropriate group (74%) compared with the Enneking appropriate group (20%). Furthermore, there was a strong correlation between first local recurrence and mortality, and there was a significantly higher risk of mortality in the Enneking inappropriate group with a HR of 3.1.[19] In a study of 103 patients with primary vertebral tumours, intralesional and marginal resections were independent risk factors for local tumour recurrence with a HR of 38.6 and 9.5, respectively, compared with en bloc vertebrectomy.[14] In one meta-analysis, the local recurrence rate was significantly greater in patients treated with intralesional resections (36.7%) compared with patients treated with en bloc vertebrectomies (9.5%).[13] Local tumour control rates were significantly higher following complete histologic excision for primary vertebral giant cell tumours (92.3% compared with 72.2% following incomplete histologic excision),[58] chordomas (78% vs 22%)[17] and primary vertebral chondrosarcomas (82% vs 0%).[16] The dog described in this case reported had a completely excised, grade I myxosarcoma. In a recent study of 32 dogs with myxosarcomas,[59] local tumour recurrence was reported in 41% of dogs, including 17% of dogs following complete histologic excision. Local recurrence and metastatic rates were significantly greater in dogs with myxosarcomas with a mitotic rate ≥10 mitotic figures per 10 HPFs (78% and 56%, respectively) compared with <10/10 HPFs (20% and 15%, respectively).[59] With complete histologic excision of a grade I myxosarcoma, the dog reported herein would have likely had a very high chance of cure had he survived his chest wall reconstruction complication.

The functional sacrifices and morbidity of en bloc vertebrectomies required to maximise oncologic outcomes should be considered in the decision-making process.[27 60] Deliberate compromise of oncologic principles should be considered if reduced morbidity and better short-term functional results are achieved at the expense of a higher risk of local recurrence.[14] Quality of life following en bloc total vertebrectomy has been investigated in two studies with conflicting results. In one study of 25 people, their quality of life in the medium and long term was similar or identical to the general population,[61] but quality of life was significantly worse than the general population in a later study of 27 people.[62] Hence, in people, en bloc vertebrectomy provides excellent local tumour control with significantly better outcomes, and it also has the potential to provide a very good quality of life for these patients. Similarly, good quality of life has been reported in paraplegic dogs following intervertebral disk extrusions.[20 21] The owner elected to proceed with surgery based on the knowledge of the care required for and the expected quality of a paraplegic dog.

The neurologic recovery in the previously performed intralesional piecemeal total vertebrectomies in two dogs and one cat were protracted and incomplete. One dog with a primary vertebral fibrosarcoma improved from non-ambulatory paraparesis to assisted ambulatory paraparesis 2 months postoperatively and to ambulatory status with normal gait, but persistent urinary and faecal incontinence, 7 months postoperatively.[22] A cat with a primary vertebral giant cell osteosarcoma improved to assisted ambulatory paraparesis 224 days postoperatively and unassisted ambulatory paraparesis with urinary incontinence at 427 days postoperatively.[23] The dog with a chronic vertebral luxation was a paraplegic prior to surgery and remained paraplegic following total vertebrectomy, but was alive 4 years postoperatively with a good quality of life.[24] The dog described in this case report was paraplegic with no deep pain sensation immediately following surgery, presumably because of myelomalacia resulting from direct iatrogenic intraoperative damage to the spinal cord, most likely during either the paramedian vertebral osteotomy or manipulation of the total vertebrectomy segment away from the spinal cord; however, other possibilities include vascular compromise to the spinal cord or bone screws positioned within the dorsolateral aspect of the vertebral canal. On necropsy, the myelomalacic changes were most severe in the T9–T12 segment of the spinal cord, corresponding to the resected vertebrae, which suggests that this spinal cord damage was a result of either iatrogenic intraoperative trauma or vascular compromise rather than malpositioned screws. For future cases, iatrogenic damage to the spinal cord during total vertebrectomy may be lessened using more precise bone cutting instruments, such as pneumatic burrs rather than an oscillating saw; and the risk of vascular compromise to the spinal cord may be mitigated in cases requiring vertebrectomy of a single vertebra rather than multisegment vertebrectomies. The neurologic deterioration was noted immediately following surgery and improved with time, with the dog returning to assisted ambulatory status in the thoracic limbs by day 14, which contrasts the typical presentation for dogs with ascending myelomalacia.[63] Based on this improvement, the mild axonal degenerative changes in the T2–T4 spinal cord noted on necropsy, and the protracted recoveries reported in previously reported total vertebrectomy cases, it is possible that this dog may have continued to improve to unassisted ambulatory status in at least his thoracic limbs.

In conclusion, total en bloc multisegment vertebrectomy is a challenging surgical procedure which may result in severe neurologic deterioration, but offers the potential for curative-intent treatment for dogs with primary vertebral tumours. The owner needs to be informed of and comfortable with the potential consequences of total en bloc vertebrectomy, and every effort should be made to minimise iatrogenic trauma to the spinal cord to maximise postoperative neurologic recovery; this includes improving the surgical technique and using separate instrumentation to stabilise the ventral and dorsal components of the vertebral canal to minimise placement of pins or screws into the vertebral column. If combining chest wall resection with total en bloc vertebrectomy, then consideration should be given to reconstructing the chest wall defect with either prosthetic mesh alone or in combination with a latissimus dorsi muscle flap.

Learning points

- ▶ Total en bloc vertebrectomy is a curative-intent treatment option for cats and dogs with tumours involving the vertebra(e)
- ▶ Total en bloc vertebrectomy provides better local tumour control and better outcomes compared with less aggressive, palliative options in people with malignant vertebral tumours while maintaining a good quality of life.
- ▶ Total en bloc vertebrectomy is a challenging surgical procedure.

Contributors All three co-authors contributed significantly to case management with JK designing and printing the patient-specific implant; SV being integrally involved in client communications and patient management preoperatively, intraoperatively and postoperatively; and SK being responsible for the patient's anaesthesia. JK provided the written description of the patient-specific implant design process. SK provided the written description of the anaesthesia for the dog. All three co-authors reviewed the manuscript and provided input on changes to earlier drafts of the manuscript.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests None declared.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement All date relevant to the study are included in the article.

ORCID iD
Julius M Liptak http://orcid.org/0000-0003-3767-7157

REFERENCES

1 Dernell WS, Van Vechten BJ, Straw RC, *et al*. Outcome following treatment of vertebral tumors in 20 dogs (1986-1995). *J Am Anim Hosp Assoc* 2000;36:245–51.
2 Rossmeisl JH, Lanz OI, Waldron DR, *et al*. Surgical cytoreduction for the treatment of non-lymphoid vertebral and spinal cord neoplasms in cats: retrospective evaluation of 26 cases (1990-2005). *Vet Comp Oncol* 2006;4:41–50.
3 Roynard PFP, Bilderback A, Falzone C, *et al*. Magnetic resonance imaging, treatment and outcome of canine vertebral chondrosarcomas. Six cases. *J Small Anim Pract* 2016;57:610–6.
4 Dixon A, Chen A, Rossmeisl JH, *et al*. Surgical decompression, with or without adjunctive therapy, for palliative treatment of primary vertebral osteosarcoma in dogs. *Vet Comp Oncol* 2019;17:472–8.
5 Boriani S, Weinstein JN, Biagini R. Primary bone tumors of the spine. terminology and surgical staging. *Spine* 1997;22:1036–44.
6 Enneking WF, Spanier SS, Goodman MA. A system for the surgical staging of musculoskeletal sarcoma. *Clin Orthop Relat Res* 1980;153:106–20.
7 Tomita K, Kawahara N, Baba H, *et al*. Total en bloc spondylectomy. A new surgical technique for primary malignant vertebral tumors. *Spine* 1997;22:324–33.
8 Tomita K, Kawahara N, Murakami H, *et al*. Total en bloc spondylectomy for spinal tumors: improvement of the technique and its associated basic background. *J Orthop Sci* 2006;11:3–12.

9. Salame K, Regev G, Keynan O, *et al*. Total en bloc spondylectomy for vertebral tumors. *Isr Med Assoc J* 2015;17:37–41.
10. Quintana LM. Primary vertebral Tumors-and Enneking was right. *World Neurosurg* 2017;99:775–6.
11. Stener B. Complete removal of vertebrae for extirpation of tumors. A 20-year experience. *Clin Orthop Relat Res* 1989;245:72–82.
12. Boriani S, Biagini R, De Iure F, *et al*. En bloc resections of bone tumors of the thoracolumbar spine. A preliminary report on 29 patients. *Spine* 1996;21:1927–31.
13. Luksanapruksa P, Buchowski JM, Singhatanadgige W, *et al*. Systematic review and meta-analysis of en bloc vertebrectomy compared with intralesional resection for giant cell tumors of the mobile spine. *Global Spine J* 2016;6:798–803.
14. Amendola L, Cappuccio M, De Iure F, *et al*. En bloc resections for primary spinal tumors in 20 years of experience: effectiveness and safety. *Spine J* . 2014;14:2608–17.
15. Hart RA, Boriani S, Biagini R, *et al*. A system for surgical staging and management of spine tumors. A clinical outcome study of giant cell tumors of the spine. *Spine* 1997;22:1773–82. discussion 1783.
16. Boriani S, De Iure F, Bandiera S, *et al*. Chondrosarcoma of the mobile spine: report on 22 cases. *Spine* 2000;25:804–12.
17. Boriani S, Bandiera S, Biagini R, *et al*. Chordoma of the mobile spine: fifty years of experience. *Spine* 2006;31:493–503.
18. Liljenqvist U, Lerner T, Halm H, *et al*. En bloc spondylectomy in malignant tumors of the spine. *Eur Spine J* 2008;17:600–9.
19. Fisher CG, Saravanja DD, Dvorak MF, *et al*. Surgical management of primary bone tumors of the spine: validation of an approach to enhance cure and reduce local recurrence. *Spine* 2011;36:830–6.
20. Levine JM, Budke CM, Levine GJ, *et al*. Owner-perceived, weighted quality-of-life assessments in dogs with spinal cord injuries. *J Am Vet Med Assoc* 2008;233:931–5.
21. Budke CM, Levine JM, Kerwin SC, *et al*. Evaluation of a questionnaire for obtaining owner-perceived, weighted quality-of-life assessments for dogs with spinal cord injuries. *J Am Vet Med Assoc* 2008;233:925–30.
22. Chauvet AE, Hogge GS, Sandin JA, *et al*. Vertebrectomy, bone allograft fusion, and antitumor vaccination for the treatment of vertebral fibrosarcoma in a dog. *Vet Surg* 1999;28:480–8.
23. Nakata K, Miura H, Sakai H, *et al*. Vertebral replacement for the treatment of vertebral osteosarcoma in a cat. *J Vet Med Sci* 2017;79:999–1002.
24. Tertuliano Marinho PV, Zani CC, De Biasi F, *et al*. Total vertebrectomy for stabilisation of chronic spinal lumbar luxation in a paraplegic dog without nociception. *J Small Anim Pract* 2014;55:538–41.
25. Krepler P, Windhager R, Bretschneider W, *et al*. Total vertebrectomy for primary malignant tumours of the spine. *J Bone Joint Surg Br* 2002;84:712–5.
26. Luzzati A, Scotto G, Perrucchini G, *et al*. Salvage revision surgery after inappropriate approach for primary spine tumors: long term follow-up in 56 cases. *World Neurosurg* 2017;98:329–33.
27. Boriani S, Gasbarrini A, Bandiera S, *et al*. Predictors for surgical complications of en bloc resections in the spine: review of 220 cases treated by the same team. *Eur Spine J* 2016;25:3932–41.
28. Izatt MT, Thorpe P, Thompson RG, *et al*. The use of physical biomodelling in complex spinal surgery. *Eur Spine J* 2007;16:1507–18.
29. Phan K, Sgro A, Maharaj MM, *et al*. Application of a 3D custom printed patient specific spinal implant for C1/2 arthrodesis. *J Spine Surg* 2016;2:314–8.
30. Choy WJ, Mobbs RJ, Wilcox B, *et al*. Reconstruction of thoracic spine using a personalized 3D-printed vertebral body in adolescent with T9 primary bone tumor. *World Neurosurg* 2017;105:1032.e13–1032.e17.
31. Liptak JM, Dernell WS, Ehrhart N, *et al*. Cortical allograft and endoprosthesis for limb-sparing surgery in dogs with distal radial osteosarcoma: a prospective clinical comparison of two different limb-sparing techniques. *Vet Surg* 2006;35:518–33.
32. Liptak JM, Ehrhart N, Santoni BG, *et al*. Cortical bone graft and endoprosthesis in the distal radius of dogs: a biomechanical comparison of two different limb-sparing techniques. *Vet Surg* 2006;35:150–60.
33. Mitchell KE, Boston SE, Kung M, *et al*. Outcomes of limb-sparing surgery using two generations of metal endoprosthesis in 45 dogs with distal radial osteosarcoma. A veterinary Society of surgical oncology retrospective study. *Vet Surg* 2016;45:36–43.
34. Aikawa T, Kanazono S, Yoshigae Y, *et al*. Vertebral stabilization using positively threaded profile pins and polymethylmethacrylate, with or without laminectomy, for spinal canal stenosis and vertebral instability caused by congenital thoracic vertebral anomalies. *Vet Surg* 2007 ;;36:432–41. Jul.
35. Sturges BK, Kapatkin AS, Garcia TC, *et al*. Biomechanical comparison of locking compression plate versus positive profile pins and polymethylmethacrylate for stabilization of the canine lumbar vertebrae. *Vet Surg* 2016;45:309–18.
36. Tran JH, Hall DA, Morton JM, *et al*. Accuracy and safety of pin placement during lateral versus dorsal stabilization of lumbar spinal fracture-luxation in dogs. *Vet Surg* 2017;46:1166–74.
37. Lewchalermwong P, Suwanna N, Meij BP. Canine vertebral screw and rod fixation system: design and mechanical testing. *Vet Comp Orthop Traumatol* 2018;31:95–101.
38. Okubo K, Wada H, Fukuse T, *et al*. Treatment of Pancoast tumors. Combined irradiation and radical resection. *Thorac Cardiovasc Surg* 1995;43:284–6.
39. Mazel C, Grunenwald D, Laudrin P, *et al*. Radical excision in the management of thoracic and cervicothoracic tumors involving the spine: results in a series of 36 cases. *Spine* 2003;28:782–92.
40. Mazel C, Balabaud L, Bennis S, *et al*. Cervical and thoracic spine tumor management: surgical indications, techniques, and outcomes. *Orthop Clin North Am* 2009;40:75–92.
41. Kent MS, Bilsky MH, Rusch VW. Resection of superior sulcus tumors (posterior approach). *Thorac Surg Clin* 2004;14:217–28.
42. Incarbone M, Alloisio M, Luzzati S, *et al*. [Chest wall and vertebral en-bloc resection for sarcoma: ten-year experience]. *Minerva Chir* 2005;60:273–8.
43. Collaud S, Waddell TK, Yasufuku K, *et al*. Long-term outcome after en bloc resection of non-small-cell lung cancer invading the pulmonary sulcus and spine. *J Thorac Oncol* 2013;8:1538–44.
44. Deslauriers J, Tronc F, Fortin D. Management of tumors involving the chest wall including Pancoast tumors and tumors invading the spine. *Thorac Surg Clin* 2013;23:313–25.
45. Foroulis CN, Zarogoulidis P, Darwiche K, *et al*. Superior sulcus (Pancoast) tumors: current evidence on diagnosis and radical treatment. *J Thorac Dis* 2013;5:S342–58.
46. Setzer M, Robinson LA, Vrionis FD. Management of locally advanced Pancoast (superior sulcus) tumors with spine involvement. *Cancer Control* 2014;21:158–67.
47. Czyz M, Addae-Boateng E, Boszczyk BM. Chest wall reconstruction after en bloc Pancoast tumour resection with the use of MatrixRib and SILC fixation systems: technical note. *Eur Spine J* 2015;24:2220–4.
48. Mazel C, Hoffmann E, Antonietti P, *et al*. Posterior cervicothoracic instrumentation in spine tumors. *Spine* 2004;29:1246–53.
49. Kienzle HF, Huzly A, Bähr R. [Thoracic wall reconstruction following extensive resection]. *Zentralbl Chir* 1987;112:451–6.
50. York JE, Walsh GL, Lang FF, *et al*. Combined chest wall resection with vertebrectomy and spinal reconstruction for the treatment of Pancoast tumors. *J Neurosurg* 1999;91:74–80.
51. Gandhi S, Walsh GL, Komaki R, *et al*. A multidisciplinary surgical approach to superior sulcus tumors with vertebral invasion. *Ann Thorac Surg* 1999;68:1778–84.
52. Jain S, Sommers E, Setzer M, *et al*. Posterior midline approach for single-stage en bloc resection and circumferential spinal stabilization for locally advanced Pancoast tumors. technical note. *J Neurosurg Spine* 2008;9:71–82.
53. Beal MW, Brown DC, Shofer FS. The effects of perioperative hypothermia and the duration of anesthesia on postoperative wound infection rate in clean wounds: a retrospective study. *Vet Surg* 2000;29:123–7.
54. 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;37:479–87.
55. Halfacree ZJ, Baines SJ, Lipscomb VJ, *et al*. Use of a latissimus dorsi myocutaneous flap for one-stage reconstruction of the thoracic wall after en bloc resection of primary rib chondrosarcoma in five dogs. *Vet Surg* 2007;36:587–92.
56. Jeong W, Lee S, Kim J. Meta-analysis of flap perfusion and donor site complications for breast reconstruction using pedicled versus free TRAM and DIEP flaps. *Breast* 2018;38:45–51.
57. Lee TJ, Oh TS, Kim EK, *et al*. Risk factors of mastectomy skin flap necrosis in immediate breast reconstruction using low abdominal flaps. *J Plast Surg Hand Surg* 2016;50:302–6.
58. Boriani S, Bandiera S, Casadei R, *et al*. Giant cell tumor of the mobile spine: a review of 49 cases. *Spine* 2012;37:E37–45.
59. Iwaki Y, Lindley S, Smith A, *et al*. Canine myxosarcomas, a retrospective analysis of 32 dogs (2003-2018). *BMC Vet Res* 2019;15:217.
60. Di Fiore M, Lari S, Boriani S, *et al*. Major vertebral surgery: intra- and postoperative anaesthesia-related problems. *Chir Organi Mov* 1998;83:65–72.
61. Mazel C, Owona P, Cogan A, *et al*. Long-term quality of life after en-bloc vertebrectomy: 25 patients followed up for 9 years. *Orthop Traumatol Surg Res* 2014;100:119–26.
62. Colman MW, Karim SM, Lozano-Calderon SA, *et al*. Quality of life after en bloc resection of tumors in the mobile spine. *Spine J* 2015;15:1728–37.
63. Castel A, Olby NJ, Mariani CL, *et al*. Clinical characteristics of dogs with progressive myelomalacia following acute intervertebral disc extrusion. *J Vet Intern Med* 2017;31:1782–9.