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Surgical repair of diaphragmatic hernia in a cat maintained on mechanical IPPV using a bain circuit

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Abstract
10-month-old female domestic shorthair cat weighing 3.2 kg was presented with dyspnea and lethargy following a fall from height. Radiographic examination revealed cranial displacement of the stomach axis, along with the spleen and mesentry, obscured visualization of the liver, and loss of the diaphragmatic line, suggestive of a diaphragmatic hernia. Surgical herniorrhaphy was performed via a ventral midline celiotomy under anesthesia induced with propofol (6 mg/kg IV) and maintained with isoflurane using intermittent positive pressure ventilation (IPPV) through mechanical Bain circuit ventilation. The diaphragmatic defect was repaired with simple interrupted sutures using 2-0 Prolene. Thoracocentesis was performed intraoperatively using a butterfly canula to reestablish negative intrathoracic pressure. Postoperative radiographs confirmed normal positioning of abdominal organs and an intact diaphragm. The cat recovered uneventfully, with sutures removed on the 12th postoperative day, and exhibited normal breathing. This case highlights the successful management of a feline diaphragmatic hernia with mechanical ventilation and surgical repair.

Keywords: Intermittent positive pressure ventilation (IPPV), Bain circuit, Herniorrhaphy

Introduction
Hernia is a surgico-medical condition, where protrusion of a part of an organ or an entire organ or tissue occurs through an opening from it's normal anatomical area to another region, under intact skin. Based different anatomical locations in the body it can be classified as abdominal, diaphragmatic or perineal hernia (Smeak,1985). Diaphragmatic hernia occurs when the diaphragm is damaged, allowing abdominal organs to move into the thoracic cavity. Traumatic diaphragmatic hernias are prevalent in dogs and cats, but the congenital form is uncommon.
Trauma, particularly motor vehicle accidents, is the leading cause of diaphragmatic hernias in both dogs and cats. A severe impact to the abdominal wall causes a rapid increase in intra-abdominal pressure. If the glottis is open, the lungs collapse quickly, creating a significant pleuro-peritoneal pressure gradient. This pressure differential between the thorax and abdomen can tear the diaphragm. These tears typically occur in the diaphragm's weakest regions, which are usually the muscular areas.
Cats had predominantly circumferential tears, with radial tears occurring at similar incidence as for combined or multiple tears. The liver is the most commonly herniated organ, with the stomach, small intestine, and spleen often involved in left-sided hernias and the small intestine and pancreas in rightsided tears.
Herniation of abdominal organs through the diaphragm is associated with compression of lung lobes, progressive atelectasis, and development of pleural effusion. Atelectasis, with or without pleural effusion, may result in significant loss of functional lung capacity and development of ventilation: perfusion mismatch and shunting. The addition of even relatively small amounts of venous blood to the arterial side of the system results in marked reductions in arterial oxygen tension (PaO2) because of the low oxygen content of shunted blood (West JB 1990)
Breathing systems are used in veterinary anaesthesia to carry anaesthetic gases and vapours to and from animals in a controlled manner. Breathing systems can be classified as

non-rebreathing or rebreathing systems. Non-rebreathing systems are categorised A–E based on the layout of their components (Mapleson 1954) with an F classification added later (Willis 1975). Only Mapleson classifications A, D, E and F are used in veterinary anaesthesia (Hughes 2016). Examples of non-rebreathing systems include Lack/mini-Lack (Mapleson A), Bain (Mapleson D) and the Ayre's T-piece These systems require fresh gas flows (FGFs) near or above minute volume to prevent rebreathing of carbon dioxide (CO_2).

Positive pressure ventilation (PPV) can have profound effects on cardiovascular function. As many patients requiring PPV may have compromised cardiac output and hypotension associated with their underlying disease process, the additive impact of PPV can further jeopardize their condition and precipitate multiple organ failure. Retrospective studies in the veterinary literature site cardiovascular collapse as being a common complication of PPV, contributing to increased mortality.

Material and methods

Upon presentation, the cat had a history of a traumatic fall from the second floor and exhibited a temperature of 102.4°F and displayed a marked dyspnoeic breathing pattern. Physical examination revealed signs of respiratory distress and vague abdominal discomfort. Auscultation of the chest showed muffled lung sounds, suggesting compromised pulmonary function. The roof palate was clear and there were no open wounds on examination.

Radiographic imaging was performed, which revealed cranial displacement of the stomach, difficulty visualizing the liver and spleen, and loss of the diaphragmatic line. The thoracic cavity exhibited unclear cardiac boundaries, and the lungs appeared to be displaced by intra-abdominal organs. These findings were highly indicative of a diaphragmatic hernia with a suspected ventral tear of the diaphragm. Additionally, abdominal ultrasound demonstrated cranial displacement of the stomach with improper margins, further confirming the diagnosis.

Given the severity of the cat's condition and suspected shock, intravenous fluid therapy was initiated immediately. The cat was administered Ringer's lactate at a rate of 90 mL/kg/hour to address the fluid deficit, and Ceftriaxone was given at a dose of 20 mg/kg IV to combat potential infection. After several hours of supportive care, the cat showed improvement, stabilizing enough to proceed with surgical intervention. A complete blood panel was done before proceeding for surgery which showed an elevated WBC, ALT and ALP.

After stabilization, surgery was scheduled for diaphragmatic herniorrhaphy. Due to the lack of access to a conventional ventilator, the decision was made to maintain anesthesia and ventilation through mechanical ventilation via a Bain non-rebreathing circuit. This circuit was employed to provide intermittent positive pressure ventilation (IPPV) and support the cat's respiratory needs during the procedure.

The cat was pre-medicated with Butarphanol (0.2 mg/kg) to provide mild sedation and analgesia and was kept on pre-oxyenation at 100ml/kg/hour. After 20 mins of pre-oxygenation anaesthesia was induced with propofol (6 mg/kg IV) to achieve adequate sedation for endotracheal intubation, which was performed without complication. Respiratory, electro-cardiogram, SpO2 and temperature were monitored during surgery. During the surgery Ringers lactate solution at the rate 2 ml/kg/hour was administered intravenously. The endotracheal tube was connected to the Bain non-rebreathing circuit, and mechanical ventilation was initiated to ensure consistent ventilation throughout the surgery. The number of mechanical bag ventilation was altered according to the Sp02 levels with initial compression of 8/min increasing up to 10-12/ min according to the patients need. Isoflurane was used for maintenance of anaesthesia, and the cat's oxygenation and ventilation were carefully monitored throughout the surgery. The IPPV was practically done with calculation of minute volume and suspected tidal volume of the cat.

The cat was positioned in dorsal recumbency, VD position. The forelimbs were extended cranially and secured gently with soft ties to facilitate full access to the cranial abdomen and thoracic inlet. The hind limbs were allowed to rest naturally, avoiding excessive tension on the abdominal wall. The head and neck were positioned neutrally, with slight elevation as needed to promote airway patency and reduce the risk of regurgitation. Throughout the procedure, care was taken to ensure that positioning did not compromise respiratory function, and slight tilting of the surgical table was avoided to maintain hemodynamic stability.

The surgical site was scrubbed in the routine manner. After adequate skin preparation, the surgical area was draped using sterile drapes, isolating the field and creating a sterile environment.

A midline celiotomy was performed extending 2 inches from the xiphoid process to the umbilicus to access the abdominal cavity. Upon entering the abdomen, herniation of the stomach and the spleen were found into the thoracic cavity. The herniated organs were carefully and gently manipulated and repositioned back into the abdominal cavity to prevent any trauma or vascular compromise.

Following reduction of the herniated contents, the diaphragm was thoroughly examined for additional defects. A single left ventral diaphragmatic tear was identified as the site of herniation. No additional tears or defects were found upon meticulous inspection. Closure of the diaphragmatic defect was performed using 2-0 Prolene suture material in a continuous suture pattern, ensuring a secure, tension-free repair.

After placement of the final diaphragmatic suture, a 22-gauge butterfly canula was used to puncture the diaphragm to allow evacuation of air from the thoracic cavity which was utilized to aspirate approximately 50 mL of air, successfully restoring negative intrathoracic pressure. This step was critical to facilitate lung re-expansion and to prevent postoperative pneumothorax.

The abdominal cavity was then carefully inspected for any evidence of organ injury, ischemia, or necrosis. The intestinal contents and peritoneal surfaces were lavaged thoroughly with sterile normal saline to remove any contaminants or inflammatory debris. Abdominal closure was carried out in routine fashion, with the linea alba closed using 2-0 Vicryl in a simple interrupted pattern, followed by subcutaneous closure and skin closure using 2-0 Prolene in an horizontal mattress.

Throughout the surgery, the cat's oxygen saturation (SpO_2) was continuously monitored and maintained between 96% and 99%, indicating stable respiratory function under anesthesia. The cat recovered uneventfully from anesthesia without any signs of respiratory distress. Postoperative radiographs confirmed proper repositioning of abdominal organs and an intact diaphragmatic contour. The patient showed an excellent recovery with normal breathing patterns and resumed normal activity shortly thereafter.

Results and discussion

Mechanical ventilation through the Bain circuit proved to be critical during diaphragmatic herniorrhaphy, as spontaneous breathing alone would likely have been insufficient to maintain effective gas exchange, particularly during the periods when the thoracic cavity was exposed to atmospheric pressure. The use of IPPV ensured continuous alveolar expansion, prevented lung collapse (atelectasis), and improved the removal of carbon dioxide, contributing to the cat's stable intraoperative condition. Moreover, mechanical ventilation helped to maintain an appropriate intrathoracic pressure gradient during surgical manipulation, facilitating easier repositioning of herniated organs and promoting a smoother diaphragmatic repair.

The effects on the patient and their body system during IPPV include:

Lung ventilation: The extent to which a patient's lung ventilation may be affected depends on the elasticity and resistance of the lungs. Accordingly, anaesthetic gas distribution will vary with the speed at which the lungs are inflated. During respiratory disease where the bronchi are constricted, the resistance of the lungs will be increased (e.g. if the lungs are inflated too rapidly, there will not be enough time for sufficient absorption of oxygen or anaesthetic gases). The inspiratory time should be increased to compensate and allow slow inflation of the lungs. An expiratory pause will be required between each breath to prevent re-breathing and hypercapnia. During disease where the elasticity of the lungs is increased (such as bullous emphysema), care should be taken to prevent rupture of bullae from over-inflation of the lungs.

C**ardiovascular function:** This is usually depressed during IPPV when compared with spontaneous ventilation. IPPV generally increases intrathoracic pressure (due to an increased inspiratory pressure) which reduces central venous pressure, and venous return to the heart, reducing cardiac output. During hypovolaemia, the venous return is further decreased By decreasing the inspiratory pressure or the time between inhalations, the thoracic pressure will be decreased, which helps to improve cardiac output.

Oxygenation: Pulse oximetry detects the percentage of oxygen saturated in haemoglobin (SPO_2) using computer software to measure the absorption of red and infrared light alongside the pulsation of the blood vessel. Assuming that the patient is receiving anaesthetic gas with a sufficient oxygen tension (PaO_2), the SPO_2 should be 100%. IPPV will mostly improve the SPO_2 of a hypoxaemic patient. However, if the cardiovascular system is detrimentally affected by the provision of IPPV, this may cause a reduced tissue perfusion — even if the SPO_2 is 100% — meaning that other methods for assessing ventilation should be considered in conjunction with PaO_2 and SPO_2.

Carbon dioxide tension ($PaCo_2$): In a healthy, non-compromised patient, an increase or decrease in $PaCO_2$ will either spontaneously increase or decrease the patient's respiratory rate and depth to provide normal ventilation. In IPPV, this mechanism is removed, meaning that monitoring the patient throughout is vital.

Hypoventilation: Causes an increase in $ETCO_2$, with the patient either re-breathing gas from the anaesthetic breathing system due to a malfunction in equipment or not ventilating enough to remove carbon dioxide. This leads to respiratory acidosis. An increase in arterial blood pressure follows, increasing cardiac workload, and tissue perfusion, leading to increased bleeding at the surgical site.

Hyperventilation: Causes a decrease in $ETCO_2$, with too much carbon dioxide being removed and respiratory alkalosis occurring, leading to a decrease in arterial blood pressure

Anaesthesia: During IPPV, the patient usually requires less anaesthetic agent than when ventilating spontaneously. This is due to the deeper breaths that are usually given to the patient during IPPV than the patient would take if they were breathing on their own. The depth of anaesthesia is often increased more rapidly than during spontaneous ventilation. Drugs which usually suppress respiration (e.g. some opioids and neuromuscular blocking agents) can be used when IPPV can be performed either manually or automatically. This will reduce the amount of anaesthetic gases required and produce a more balanced anaesthetic

Following herniorrhaphy and reestablishment of negative thoracic pressure via thoracocentesis with a butterfly canula, the lungs re-expanded successfully, and the cat was weaned from mechanical ventilation without any evidence of respiratory distress. Postoperative thoracic radiographs confirmed the correct anatomical positioning of the abdominal organs and an intact diaphragm with normal radiographic cardiac and pulmonary outlines. The animal recovered uneventfully, regaining normal respiratory function within hours after surgery and displaying no signs of hypoxia, tachypnea, or dyspnea during the postoperative period.

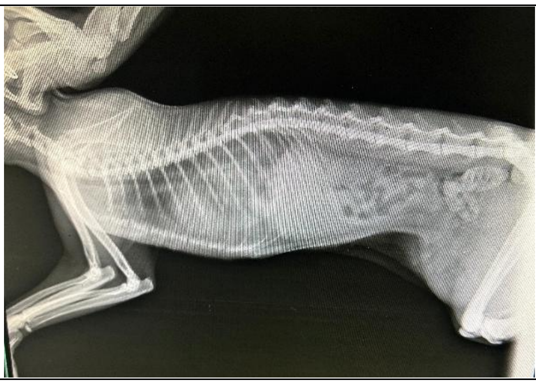

Fig 1: Radiograph on the day of presentation Lateral View

Fig 2: VD View

Fig 3: Pre-oxygenation and IVFT

Fig 4: VD Position for Surgery and Scrubbing of Surgical Site

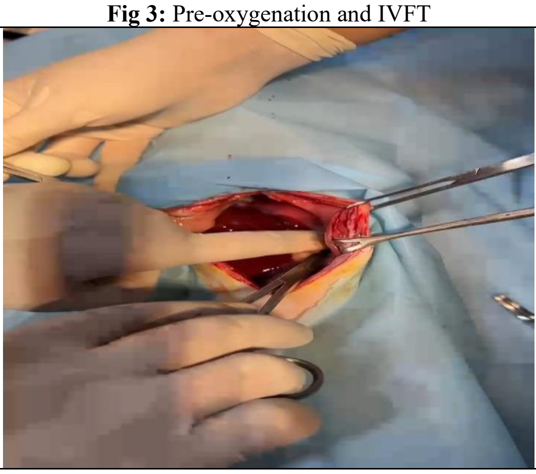

Fig 5: Identification of ventral tear of diaphragm

Fig 6: Mechanical Ventilation to maintain IPPV through bain circuit

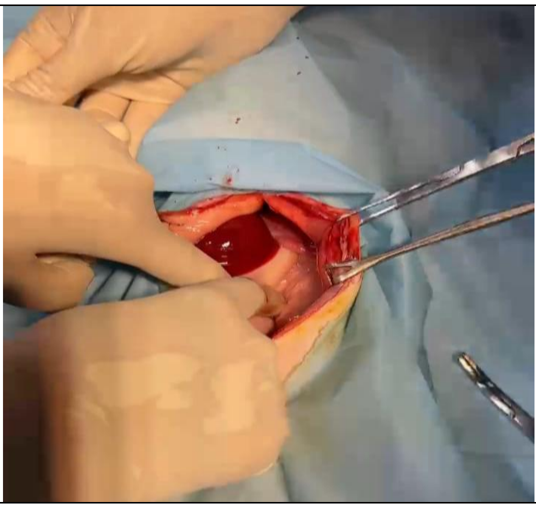

Fig 7: Gentle Separation of Hernia content from the thoracic cavity

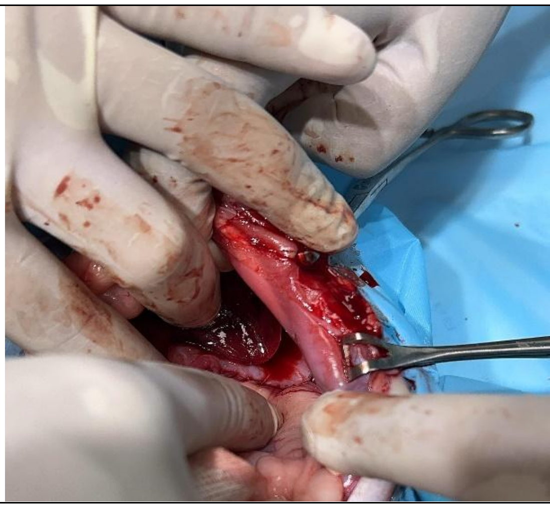

Fig 8: Herniorraphy using 2-0 Prolene

Fig 9: Mechanil ventilation with bain circuit with constant monitoring through pulse oxymetry and capnogram

Fig 10: Post Surgery radiograph indicating successful repair of the diaphragm

Fig 11: Patients recovery and all vitals normal after surgery

Fig 12: Normal vitals post 3 days of surgery

Conclusion

Intermittent Positive Pressure Ventilation proved to be an effective and reliable supportive therapy for maintaining adequate oxygenation and ventilation in feline patients undergoing general anaesthesia or presenting with respiratory insufficiency. Its use was particularly beneficial in cases with compromised pulmonary function, trauma, or diaphragmatic hernia, where spontaneous ventilation alone was inadequate. With careful monitoring of airway pressure, respiratory rate, and blood gas parameters, IPPV minimized peri-anaesthetic hypoxia and hypercapnia, contributing to improved surgical outcomes and recovery rates. Hence, the implementation of IPPV under controlled settings can be considered a vital component of modern feline anaesthetic management and critical care. It could also be used efficiently in canine neonatal care and feline anaesthetic management.

Conflict of Interest

Not available

Financial Support

Not available

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